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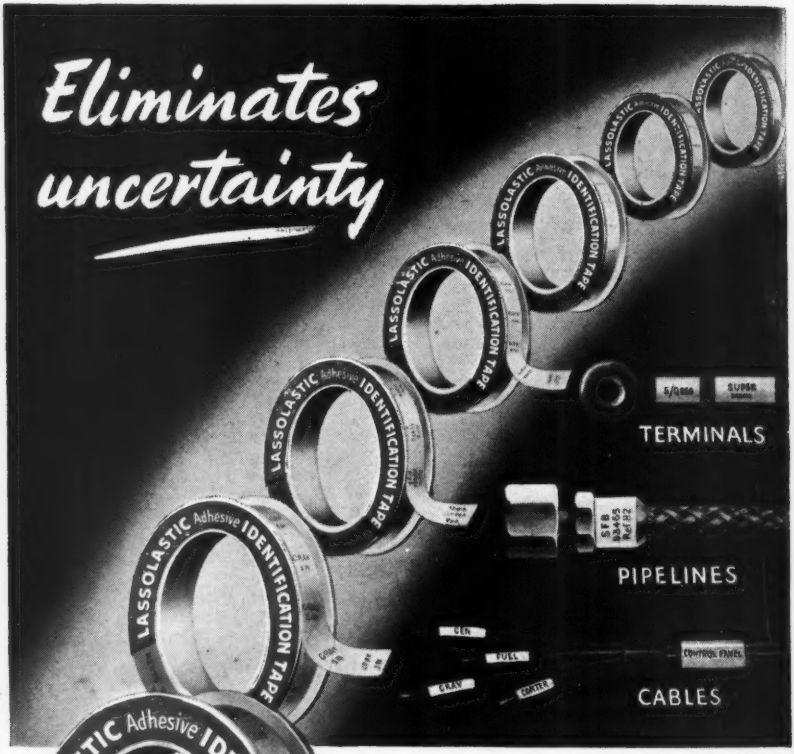

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Sir Herbert Morgan on Reconstruction

AT the annual general meeting of Crystalate, Ltd., held on December 15th, 1943, at Winchester House, E.C., the Chairman, Sir Herbert Morgan, K.B.E., said: It will be seen from the report that there has been an increased profit on trading and that the liquid position of the company is most satisfactory.

The net profit for the year, before charging taxation, amounts to £46,407. Last year it was £37,029. When, however, I come to the deductions for taxation the comparison, unfortunately, is not so favourable, the charge being £35,085, compared with £9,366 last year. This leaves a net balance of £11,322, compared with £27,663 for 1942.

During the year we have received from the British Homophone Company, Ltd., a dividend of £10,170 gross. The net profit of that company, after taxation, is higher by £6,000, or nearly 50 per cent.

Our liquid capital remains satisfactory. This amounts to £93,027, as against £100,746 last year.

Reconstruction Foreshadowed

The "Assets Deficiency" account remains the same as last year at £173,822, which represents the capital lost during the period—some years ago—when the company was mainly engaged in the gramophone record industry and before the Board, as now constituted, were in control.

I advised the shareholders last year that a plan of reconstruction was receiving the Board's consideration. We are now preparing, in consultation with our professional advisers, a scheme for the reconstruction of the capital of the company, which we propose to place before the shareholders in the course of the current financial year. I do not propose to go further into the matter at this stage, beyond saying that a recommendation will be made that the "Assets Deficiencies" account must be eliminated.

This proposed reconstruction would have been undertaken before, but it was impossible until we had arrived at an agreement with the Inland Revenue as to our excess profits tax position and until we could formulate something approximating an exact idea as to what our profit earning capacity was. Subject to being placed on a proper capital basis, I regard the prospects of your company as good. We are engaged in an industry which is on the upgrade and for whose products I foresee a continued demand in the post-war period.

Future of Plastics

While I have not that visionary idea of the future of the plastic trade which has been somewhat loosely promoted, I do firmly believe that for those businesses efficiently organized, equipped and capitalized and engaged on essential work, there is a future of reasonable prosperity in store. I know that we were making the right type of products for post-war requirements before the war and that our resources, staff and equipment will enable us to get our full share of orders when we return to our standard type of business.

While there has been far-reaching employment of new plastic processes and materials for the purposes of war, their direct application to peace-time uses has yet to be demonstrated. But there is no doubt that the industry has made great progress in the past four years and there will be many benefits to be enjoyed by it when its purposes are those of supplying the normal demands of the consumer.

I should like the shareholders to realize that the plastic moulding capacity of the country has increased during the last few years. Let us hope this will not bring about a recurrence of the uneconomic competition which existed before the war.

Post-war Planning

This company will be directly affected by the national housing policy. The need for plastic fittings and accessories in the building and ancillary industries will undoubtedly provide us with a large amount of work and it is fairly safe to assume that the demand will be an increasing one.

The national change over of industry must be one of the very important details in any schemes which Lord Woolton as Minister of Reconstruction will no doubt be considering. The day will come when munition contracts will be cancelled, resulting in some temporary stoppage of work. Plans to lessen this to the minimum call for a measure of preparedness. This planning is a very formidable task for the individual industrialist without more precise information from the Government on their policy. In particular, the business community await knowledge on such problems of the future as the demobilization of skilled workers, priority of materials, transport, profits and control. Further, they must have warning of the intentions of the authorities in regard to imports and exports and the disposal of Government stores, factories and machinery.

Speaking generally, in relation to the building industry, my belief is that huge scale demand for building fittings is so certain that the Government should accept at the earliest possible moment the responsibility for placing large orders in the manner of the Ministry of Supply for providing essential units in housing.

The establishment of a Department of Supply by the Ministry of Works for the building trade would help to shorten the period of change over in those industries now engaged on war work, but normally making fittings for houses. My belief is that some such organization is vital in order to speed up the provision of housing and for the prevention of unemployment.

The individual manufacturers will be straining at the leash to regain trade lost and must not be kept waiting because it is the industrialist who can create plans for work when he has guidance from the Government.

The report and accounts were adopted.

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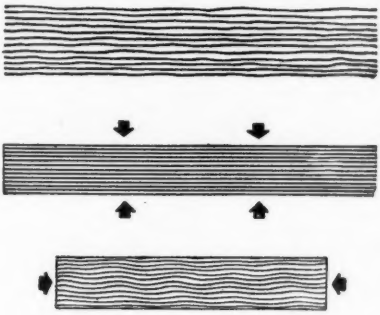

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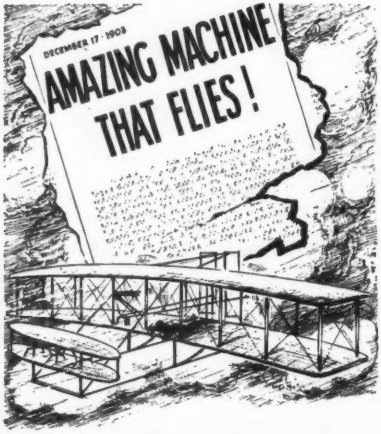

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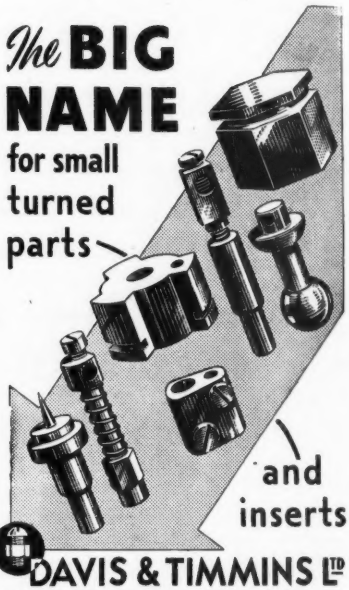

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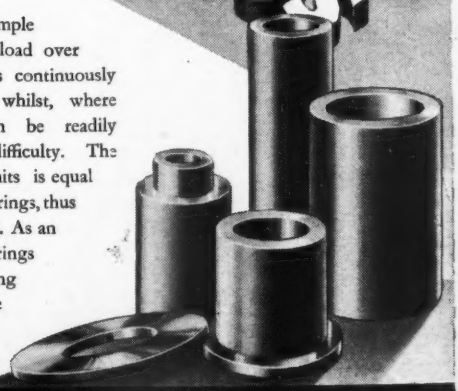

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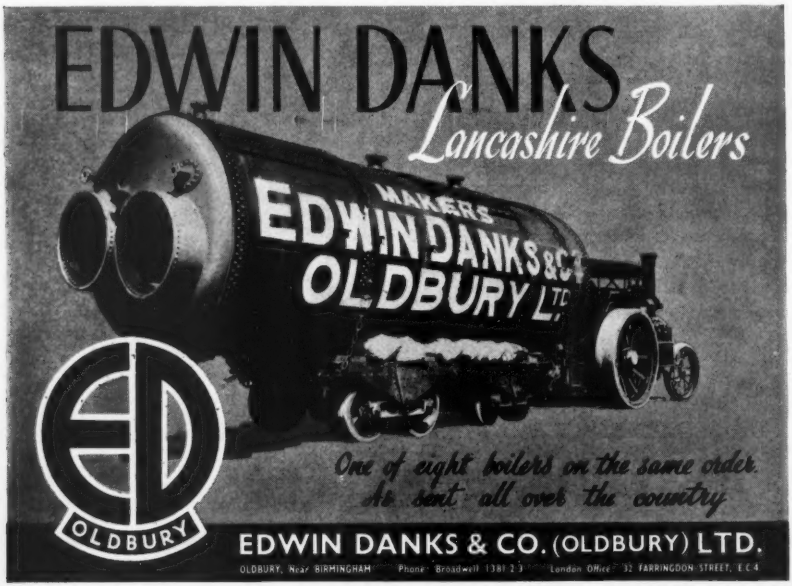
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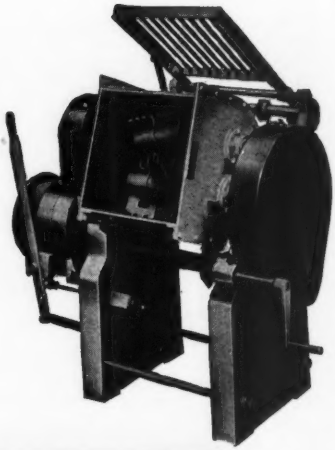

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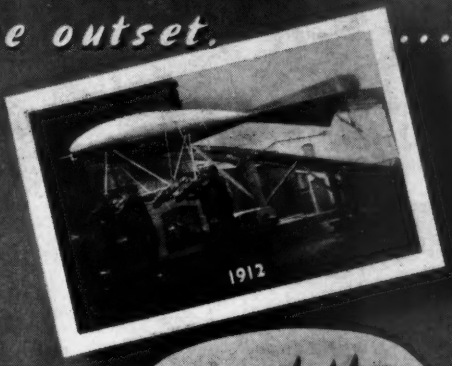

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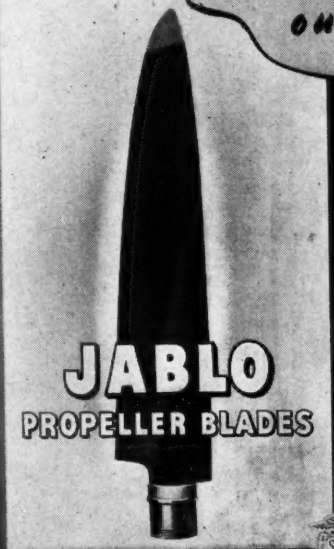

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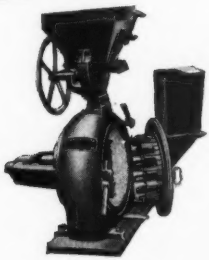

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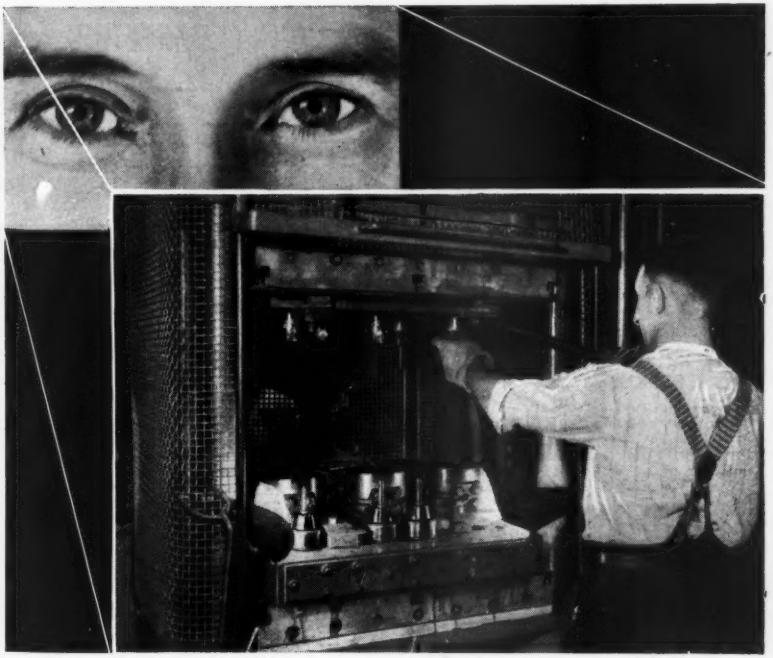

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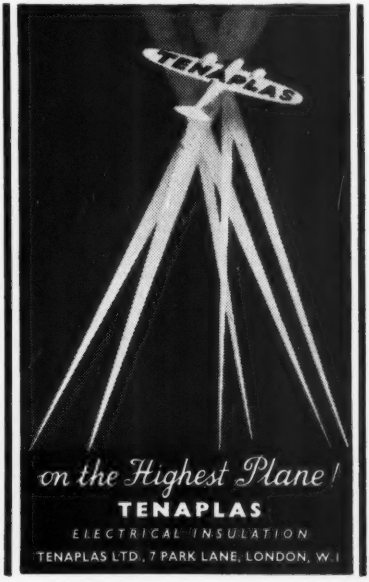

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Pioneers in the Plastics World

Vol. VIII. No. 80 JANUARY, 1944

Plastics

Dealing with the Manufacture, Uses and Potentialities of Plastic Materials

Proprietors - - TEMPLE PRESS LIMITED
Managing Director - ROLAND E. DANGERFIELD

Editor - M. D. CURWEN, B.Sc., A.I.C.
Offices - Bowling Green Lane, London, E.C.1

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NOTICES

All instructions, matter and passed proofs for all kinds of advertisements must reach the Head Office of "PLASTICS" by the 24th of each month to ensure insertion in the following month's issue.

TERMS—Monthly accounts, strictly net; due when rendered.

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SAVE PAPER

More than ever is paper waste required for our war industries. Waste paper makes munitions in a hundred forms—from shell cases to aeroplane parts.

The fact that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

EDITORIALS

The New Year

WE may look back with considerable satisfaction on the old year, which has been one of important achievement by the plastics industry. In looking forward we wish all our friends a year of success. May it also be Victory Year and the end of the war in Europe so that we may go upon our lawful occasions once more.

High-frequency Moulding

INDUSTRIAL endeavour may be likened generally to a somewhat placid river that flows serenely from source to mouth, growing wider, it is true, but very slowly. Some rivers, however, on occasion, by the sudden irruption into them of rushing streams, have their whole courses and their qualities changed.

We do not wish to carry this analogy too far, but something very much like it is happening to the plastics industry.

It has been our pleasure from time to time to record of this fascinating industry of ours a sufficiently ingenious and useful number of inventions, of important new discoveries in raw materials, of the development of new applications and so on. The young stream has never been entirely placid—it has been slightly turbid; but it was never very turbulent, any disturbance in the flow being due rather to anticipated increments.

The advent of high-frequency technique and its application to moulding appears very likely to change the stream to a good-sized river of considerable clarity and purity.

Mr. George Dring, of Bakelite, Ltd., gave us last month a very stimulating view of the possibilities of this new process at a meeting of the Institute of the Plastics Industry, and we are exceedingly grateful to the Institute for permission to reproduce his story in this issue. At the same time we must record our pleasure at the celerity with which his company has introduced the process into this country, with the knowledge that it may be adopted without hindrance by anybody who chooses to do so.

The use of high-frequency currents as a means of producing heat is by no means new, and we can delve into the late 19th century and find that the early experiments of the induction heating of metals was then carried out.

The heating of amorphous materials and dielectrics, however, was not a simple matter. More than 10 years ago rubber was so treated as a means of curing, and it is only during the past seven years that experiments on synthetic resins have been carried out. They have now suddenly been crystallized into a fully fledged method, revolutionizing our conception of moulding time cycles, pressures, and of producing high-quality strong mouldings.

This paper is so important that Mr. Dring will be giving it again in Manchester on February 5, Birmingham on February 25, and Glasgow on April 29.

Collaborative Research

IF ever there was need for collaborative research in the industry it is now, and yet how difficult it is to get a number of individuals to sit down together to hammer out ways and means. There is very loud agreement as to its necessity, but much of it is mere lip service, a cloak to prevent the accusation of reactionism or unwillingness to share knowledge.

No doubt with sufficient backing a section of the Department of Scientific and Industrial Research could be created. Perhaps, too, such a preliminary step may be necessary to obtain Government aid, for the industry is far from being financially a large one.

How much more satisfactory, however, would be a Research Station, run by plastics technologists with money raised

solely by the industry and completely controlled by it. If only individual concerns would realize the importance of raising the general efficiency of the whole, which would bring an ever-widening market for all in which to benefit! There need be no sacrifice of individual and specialized research, for there are hosts of problems generic to all.

It is a strange fact that an industry can and very often does readily unite to form price conventions or to raise a fund for co-operative publicity, so that some measure of protecting or increasing trade is thereby reached. But there is far more money to be made by increasing our knowledge about our industry and thereby widening the use of its products than by all the publicity and cartels.

New Year Honours

We have much pleasure in announcing that Mr. J. H. Chalk, works manager of Bakelite, Ltd., has been awarded the M.B.E. for services rendered.

Plastics and the Mechanical Engineer

Notes on two papers delivered before the Institute of Mechanical Engineers by S. Livingston Smith ("A Survey of Plastics from the viewpoint of the Mechanical Engineer") and J. L. Daniels ("Moulding Plant for Plastics").

AT the meeting only a short synopsis of the papers was given extending over only 20 minutes each, so that just the most interesting, intimate details of the research work carried out could not be given. Dr. L. Smith is head of the engineering department of the N.P.L. and Mr. Daniels joint managing director of the well-known firm of press manufacturers. In the report to be published it should be stressed that this method of presenting papers should be discouraged, as just the main purpose of such lectures, the advancing of specific ideas, is defeated. It is further deplorable that the greater part of the lantern slides containing tables could not be read.

The paper of Dr. L. Smith is the result of actual research into the strength and service data of various types of plastics and valuable comparison data with metals and woods are given. The paper of Mr. Daniels is of more practical points of view and contains several new and improved designs; from his data it seems that the up-stroke press is still the preferred type in this country, in spite of the indisputable advantages of the down-stroke press.

The discussion was very interesting and lively; one speaker stressed the point that actual strength data for plastics were hitherto lacking and before such data have been established the practical engineer will prefer materials for which his usual empirical formulas are applicable. It was said that Dr. L. Smith has made a useful contribution to the problem of low-pressure moulding and this should be the future trend permitting the use of cheaper moulds and avoiding the great trouble in the production of the present-day moulds, even when using the hobbing process. Dr. N. A. de Bruyne, of Aero Research, Ltd., was going farther into this problem and mentioned that it is possible to reduce the moulding pressure to 200 lb./sq. in., and Mr. Young sketched a continuous moulding plant using a steel belt to press the laminated material continuously, avoiding the actual pressing operation with obvious reduction in costs. Mr. Young further gave actual figures of prices of various artificial materials on the basis of price per pound, showing that the plastics still range very high and only by improved and perhaps novel production methods, being the legitimate field of the mechanical engineer, competition with the older materials such as hard rubber and wood could be achieved. Dr. De Bruyne, in spite of having himself developed improved plastics, showed by a diagram that the cellular synthetic materials have attained the strength of wood only for a relatively low ratio load/length^2, but not for higher ratios. Further problems mentioned were improvements in hydraulic pumps, and calculations of heat transmission.

P.G.

Metallizing Plastics
(continued)

A Complete Survey and Critical Study of the Modern Methods of Metal Film Formation on Plastics for their Protection and Decoration

by
E. E. HALLS

8. Electroplated Metal Coatings (contd.)

American Method

An American process for electroplating plastics introduced during the past few years incorporates some of the features mentioned above, but is also interesting because it uses a tin solution. The operations entailed can be summarized as follow:—

(a) Clean in mild aqueous alkali solution.

(b) Wash in water.

(c) Immersion treat in a dilute acid solution.

(d) Wash in water.

(e) Soak in tin (stannous) chloride solution.

(f) Wash in water.

(g) Apply the bonding and conducting coat. The medium used contains the silver and the vehicle is a solvent that softens the plastic surface to enable adhesion of the silver to be assured.

(h) Wash in water.

(i) Copper plate from an acid electrolyte.

(j) Water wash.

(k) Dry off or follow with any other plating, polishing or colouring operation that may be desired.

Small components can quite satisfactorily be treated in barrels.

A U.S. Patent covering tin chloride process is No. 2214646. It claims the process to be applicable to hard rubber, phenolic and amino resin products, to the various cellulose derivatives, and to other synthetic plastics. Further, it extends its claims to porous materials such as wood and plasters, which first have to be sealed with a priming lacquer. The various synthetics offer plenty of scope for providing this primer coating. The processes differ somewhat from those just outlined and include the following:—

(a) " Depolishing " either by sand blast or by solvent.

(b) Cleaning in mild aqueous alkali, followed by washing.

(c) " Depolymerizing " in concentrated stannous chloride solution, followed by washing.

(d) Silvering.

In the depolishing process, masks or stencils may be used so that some areas are left untreated and these will not silver. Thus patterns can be obtained. Masking can, of course, also be done by means of adhesive tape, etc.

The depolymerizing time is determined by the nature of the plastic and may require from 30 mins. to 1 hr. or more.

Varieties of Silver Bath

The silver bath is mixed from two solutions, one of sodium potassium tartrate and silver nitrate in water, and the other of silver nitrate and ammonia, also in water. The thickness of the silver deposit is determined by the time of immersion in the agitated solution. The silver coat is sufficiently robust to withstand polishing by buffing or by barrel tumbling, and it can itself provide the final finish, it may be lacquered or coloured, or it may serve as the base for any other electroplate deposit from the orthodox plating baths.

The fact that chemical silvering is achieved from aqueous solutions and that

the electroplating processes likewise use aqueous solutions with water washes involved renders this procedure very attractive for plastics because it enables all the operations to be performed in succession along a plating line akin to that adopted regularly in industrial finishing shops for metal components. Routing the work to the lacquering department for preliminary bronzing treatment, or to a special section for graphiting, can be eliminated, therefore the possible objection of expense which may arise at first sight can be offset. It is along these lines that satisfactory mass-production plating is most likely to develop, especially for small plastic articles like buttons, clips, knobs, jewellery, which can be mass handled in barrels. J. R. Hepburn, in an article on silver coatings in "Metal Industry" (London), August 8, 1941, deals in great detail with the perfection of silvering methods, not only for glass, but also for other non-metals, including the cellulose derivatives and plastics generally. This is considered to open up such possibilities for the future that the practical data he gives on silvering is abstracted in the following.

Hepburn stresses the advantages despite cost of silver over copper bronzing and graphite, and particularly emphasizes the practicability of obtaining silver coats by immersion of uniform thickness over all surfaces of the object, however intricate it may be. He discusses preliminary cleaning which is essential to remove greasiness, either in suitable solvent or aqueous alkali. He refers to weak acid dips, but particularly lays stress on an immersion treatment in stannous chloride. He terms this a "priming" treatment upon which success of the silver process is stated to be dependent.

Hepburn has found stannous chloride at concentrations between 5 and 10 per cent. to be quite successful. It is applied normally by simple immersion, although it may be applied by gentle swabbing with cotton wool. It is essential to wash in water to remove any excess adhering stannous chloride, otherwise the silver deposit may be mottled. There is no need to fear the removal of all the stannous chloride by the water rinsing because evidence shows this is quite strongly absorbed at the non-metallic surfaces. Straight from the water rinse without drying, the work is passed to the immersion silver process. Some workers recommend that the work should be somewhat warmer than the silvery solution. It is thus advantageous to immerse in warm water.

Hepburn refers to the following range of silver solutions:—

No. 1. The Brasher Cane Sugar Formula

This gives excellent results in cold solutions, but temperatures from 20 to 30 degrees C. are best. The following solutions are involved:—

Reducing Solution A:
- Sugar, 100 gms.
- Nitric acid (S.G. 1.22), 5 ml.
- Alcohol (64 OP methylated spirit), 200 ml.

Silver Solution B:
- Silver nitrate, 10 gms.
- Water, 1 litre.

Ammonia Solution C:
- Ammonia (S.G. 0.880), 200 ml.
- Water to 1 litre.

Potash Solution D:
- Potassium hydroxide, 100 gms.
- Water, 1 litre.

In use, to 200 ml. of silver solution B ammonia solution C is added drop by drop with constant stirring until the yellowish-brown precipitate of silver hydroxide is just redissolved. Then, 10 ml. of the potash solution D is added. A brown precipitate again forms and is just redissolved by cautious addition of ammonia solution, avoiding too great an excess.

To 200 ml. of the silver solution thus treated, 10 ml. of reducing solution A are added.

No. 2. Formaldehyde Formula

Reducing Solution A:
- 500 ml. of formalin (40 per cent. formaldehyde solution) diluted to 1 litre with water.

Silver solution B and ammonia solution C as in No. 1 above. 200 ml. of silver solution B is treated with ammonia solution C as in No. 1 (but no potash is used), and then 20 ml. of the reducing solution A is added.

No. 3. Rochelle Salt Formula

Reducing Solution A:

Rochelle salt, 100 gms.
Water, 1 litre.

Solution B, C and D as in formula No. 1.

To 200 ml. of silver solution B treated with solutions C and D as in formula No. 1, 20 ml. of reducing solution A are added. This solution is used cold.

When electroplating, areas may be "stopped-off" with lacquer if desired. Also adhesion of the silver deposit may be augmented for electroplating if required by "quicking" with a dilute solution of mercury cyanide, applied by brushing or dipping.

It is not certain that silver deposition occurs directly upon the base material, but it may be first precipitated in the solution and then deposited. For this reason the minimum of solution required for the purpose must be used, although silver can be recovered from spent solutions. For this reason, large articles are treated singly with constant agitation, and the process has prospects of being best for barrel treatments of small articles.

Copper plating from an acid bath is most generally first applied to the conducting coats of all types. One such bath is as under:—

Copper sulphate crystals	28 oz.
Sulphuric acid (S.G.1.85)	6 oz.
Ammonia alum	2 oz.
Water	1 gal.
Corn molasses as brightener	2 pts./1,000 gals.

The solution may be agitated with compressed air in the normal way, and deposition started at 1 volt and later stepped up to give a current density of 20 amps./sq. ft., then depositing copper at a rate of 0.001 in./hr. It is generally stated that the low current density plating should extend to about three hours.

The Graphite Film in Electroplating of Plastics

The following is a brief summary of some experimental work carried out in relation to the possibility of electroplating plastics by simple methods and the adhesion of the electro-plate coatings so obtained. In all these tests the material used was bakelite paper laminated of high grade. The natural highly glazed surface of the material was roughened by lightly shot blasting.

A graphite solution was first considered to give superficial conductivity. The graphite solution was made up from one part of "aqua-dag," one part of 15 per cent. potassium bichromate solution and two parts of distilled water by volume. The mixture was applied by brushing and allowed to dry. A specimen so produced would withstand vigorous brushing with a clean, dry cloth without very perceptible removal of the graphite coating. When they were vigorously brushed under flowing hot water, the coating was removed in places, leaving bare areas. Attempts to plate test pieces of this material failed because the surface resistance was excessive, being of the order of 2,000 sq. ohms.

By brushing a second coat of graphite, after allowing the first one to dry, and then lightly wire brushing the dried surface, some improvement in the conductivity was obtained, but conductivity was not sufficient to permit of copper plating.

The Use of Metal Powders

Various tests were also made using metal powder lacquers as the conductive layer. In general it was found that they were not sufficiently conductive, e.g., the following mixture gave a film which when tested across the diagonal of the test piece (rectangular 2 ins. by 3½ ins.) gave a resistance of the order of 1 megohm.

Cellulose bronzing medium ...	1 part by volume
Diluent	2 parts by volume
Bronze powder ...	1 part by volume

However, it was found that the speci-

mens with the double coating of graphite or with the bronze medium could be rendered conductive by an immersion treatment in silvering solution ($3\frac{1}{2}$ oz. of sodium cyanide and 3 oz. of silver nitrate per gallon of water). They copper-plated satisfactorily, although the adhesion was not very good and the copper layer could be scraped off with the thumb nail. It was also possible to plate the bronze lacquered specimens if they were immersed for about two minutes in a hot solution of sodium cyanide, 15-20 per cent. by weight. Again the copper deposit could be removed relatively easily by means of the thumb nail.

Tests using copper powder instead of bronze powder were made. In this case the lacquer mixture was as follows:—

Cellulose bronzing medium	...	1 part by volume
Diluent	...	1 part by volume
Copper powder	...	1 part by volume

The resistance of the coating measured across the diagonal was of the order of 40 megohms, and it was unsuitable for direct plating.

Some of the bronze-coated pieces silvered by immersion and copper plated to a thickness of about 0.0002 in. (20-30 mgms. of copper per sq. in.) were tested for adhesion after completion of the plating and drying. Adhesion was good—very good, in fact—and the copper could not be removed by scratching. On the other hand, when the coating was tested before drying or even after rewetting, the adhesion was poor. In this way copper from acid copper sulphate solutions up to 0.001 in. in thickness (140-160 mgms. of copper per sq. in.) were successfully applied.

Fig. 24.—Tilting plating barrel. (Cruickshank, Ltd.)

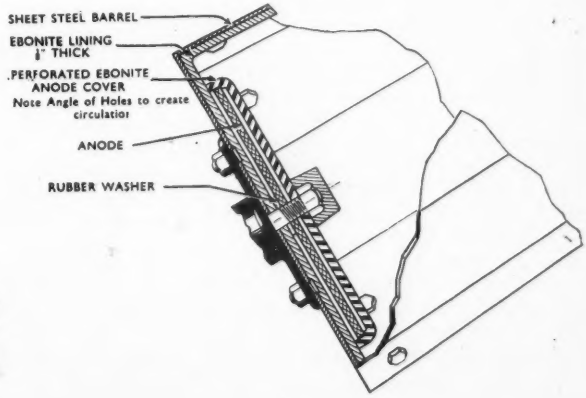

Fig. 25.—Design of the electrical connections used in the plating barrel shown in Fig. 24.

Nickel and Cadmium Plating

Nickel was applied from a normal nickel sulphate bath, using a current density of 10 amperes per sq. ft. and obtaining 0.00075-in. thickness (about 100 mgms. per sq. in.) in two hours.

Attempts to directly silver the bakelite laminated specimens by boiling in a mixture of 1 oz. of silver oxide and 15.5 ccs. of strong ammonia per gallon of water were not very successful. Zinc plating from an acid sulphate bath was applied over the copper bronze and immersion silvered quite satisfactorily. Adhesion and appearance were both quite reasonable. Current density was of the order of 10 amperes/sq. ft., and voltage of the order of 4 volts. Plating times up to 2½ hours were employed, and thicknesses of zinc up to 0.0015 in. (160 mgms./sq. in.) were obtained.

Cadmium was applied on similarly prepared specimens, using the normal cyanide bath and a current density of 10 amperes/sq. ft. voltage 2½ volts. Plating times up to two hours were employed, and deposits up to 100 mgms. of cadmium per sq. in. satisfactorily obtained. Adhesion was quite reasonable and appearance normal.

Some metal-sprayed samples were investigated, because they are often referred to as the basis for plating. Specimens zinc sprayed by the wire pistol method were satisfactorily plated with zinc from an acid zinc sulphate bath yielding good appearance and good adhesion. However, there is no purpose in adding plated layers to metal-sprayed coatings unless there is some specific reason to justify it, e.g., metal colouring, high-frequency electrical conductivity, etc. However, such requirements can usually be met by direct metal spraying or by electroplating methods alone, preferably the former.

Plating Electrolytes

The plating electrolytes referred to in the summary of the investigation work are given below:—

Copper sulphate bath:—
- Water, 1 gal.
- Copper sulphate crystals, 20 oz.
- Sulphuric acid, 3½ oz.
- Glucose syrup, ¼ oz.

Nickel sulphate bath:—
- Water, 1 gal.
- Single nickel sulphate, 24 oz.
- Sodium chloride, 0.5.
- Boric acid, 1.5.
- pH value, 5.4 to 5.6.

Zinc sulphate bath:—
- Water, 1 gal.
- Zinc sulphate crystals, 60 oz.
- Aluminium sulphate, 2 oz.
- Sodium chloride, 2 oz.
- Glucose syrup, 1½ oz.
- pH value, 4.0 to 4.5.

Cadmium cyanide bath:—
- Water, 1 gal.
- Cadmium oxide, 6 oz.
- Sodium cyanide, 14 oz.
- Dextrine, 0.5 oz.

Plating Plant

This section on the subject of electroplating plastics opened upon a warning note concerning quality of coating and indicating complexities of process. The subject has run to considerable length despite attempts at brevity. The treatment of it bears out fully the complexities to be encountered, the technical approach and practical skill required. The individual attention suggested by some workers is only practicable for large work, although it may be feasible in barrel processes providing that a batch can be considered as receiving this individual consideration. Figs. 24 to 27 show typical types of barrel used by electroplaters to indicate plant available. Some of the later processes described—solvent roughening, aqueous stannous chloride preparation, silvering treatment, as well as the final plating, can be carried out in such equipments. These provide for mass treatment and agitation. The type shown in Fig. 24 (its construction shown in Fig. 25) can be obtained in small sizes; treated work is removed by tilting and catching in a wire basket over a portable tank. The work can, therefore, be readily washed and passed to the next barrel, while the solution is returned to

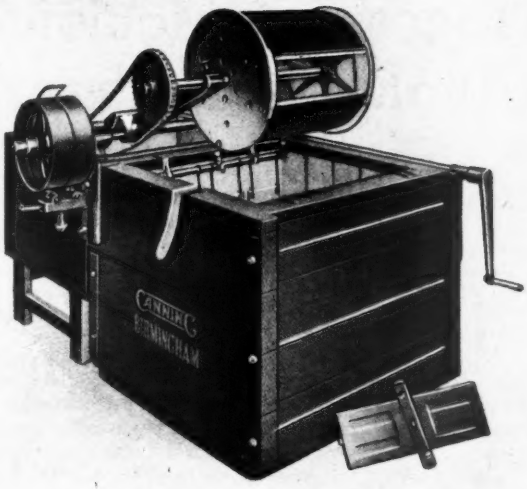

Fig. 26.—"Quickplate" plating barrel. (Canning and Co., Ltd.)

its previous barrel for further use. The plating solution has an internal anode suspended in the solution; anode area can thus easily be adjusted, and so can current density to the low values required. Another type shown in Fig. 26 is usually of larger capacity, requires two tanks, one of the solution in question and one of flowing wash water. The barrel is rotated horizontally in the treatment solution and then swung over and rotated in the wash water. The volume of solution necessary is obviously larger than with the first type of barrel. Several firms manufacture these barrels in standard sizes, although they can be constructed to suit individual's needs or by the users themselves. Hard rubber, bakelized fabric, rubber-covered metal and rubber-covered wood are the usual materials of construction. A smaller type of barrel for rotating in a still tank of solution is shown in Fig. 27. It can be seen, therefore, that no difficulties will arise with respect to plant, but that the next stage of development must be practical exploitation by prospective users.

Fig. 27.—"Midget" plating apparatus. (Canning and Co., Ltd.)

It is interesting to note that an American patent covers the use of electroplating of multiple electrical connections after printing them in conducting ink upon insulating material.

A non-conducting material such as card or plastic is stamped, using a rubber pad and a conducting ink, presumably graphite, with a facsimile of the desired connections, after which they are built up by electroplating. Thickness of plating can be as desired.

All the connections on the card can be so plated, but where disconnections are required, i.e., no continuity of circuit, this can be achieved after plating by blanking, punching or otherwise cutting away the material over the area of the disconnection.

(To be continued)

D

A New Process of Moulding Using High Frequency

An abstract of a paper read by George Dring, M.A., B.Sc., F.I.C., M.I.Chem.E., Research and Development Manager, Bakelite, Ltd., before the Institute of the Plastics Industry on Dec. 14, 1943.

This paper is the copyright of the Institute of the Plastics Industry and would normally be published first in the Institute Transactions, but owing to the keen interest which has been shown it has been decided to permit pre-publication.

MR. DRING began by assuring the moulding industry that it need not understand all about electronics and valves and oscillators in order to use the new process of moulding in their works. The actual apparatus for producing high-frequency heating is the job of the electrical engineer and should be as simple to use as a radio set. He was not, therefore, going to give an account of the science of high-frequency heating. What does interest the moulder is what he can do with the new process, and that was the subject of his talk.

Conventional Moulding

Before we go any farther in regard to the new process of moulding using high-frequency heating, said Mr. Dring, let us consider one or two points with regard to the conventional moulding cycle as at present used. Fig. 1 shows a very simplified drawing of a flash mould in the form of a beaker. When a cold powder or cold pellet is put into a hot mould, the moulding material in contact with the hot surface of the mould is raised to fluxing temperature. The heat transfer through the bulk of the powder is relatively slow, and if the bulk of the powder is very great the material in contact with the walls of the mould may be fully cured before the heat from the mould surface has reached the centre of the moulding powder mass. As the mould is closed, however, the softening moulding powder is pushed by the external pressure into the shape of the final mould, and if, as is generally the case, turbulent flow of the powder takes place in the closing of the mould, a considerable portion of the powder may come in contact with the heated walls of the mould and be reasonably well fluxed. This, however, depends entirely on the shape of the mould, and in some moulds there is relatively little flow of moulding powder and practically the whole of the heat which reaches the bulk of the powder

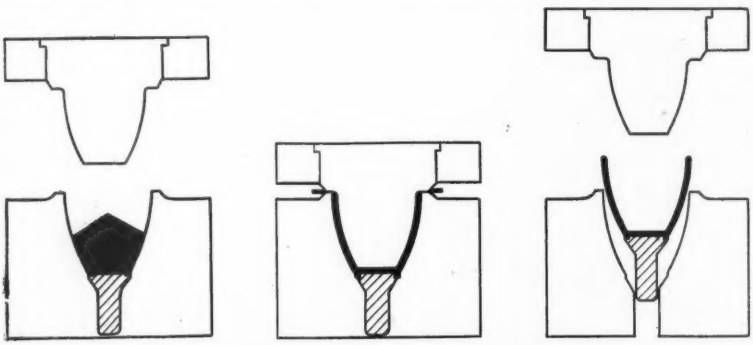

Fig. 1.—Diagrammatic representation of conventional moulding practice.

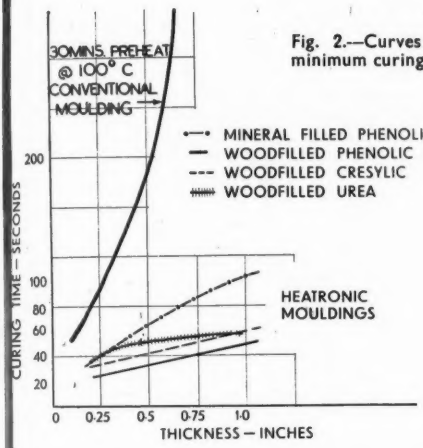

Fig. 2.—Curves showing relationship between minimum curing time and thickness of moulding.

is transferred by conduction through—and this is a very serious point—a relatively non-conducting mass. Even when the pressure has shaped the softened mass, further heat has to be transmitted through this same relatively non-conducting material to cause the full polymerization of the moulding material to give the final cured moulding. For this reason the curing time by conventional means increases rapidly with increasing thickness of the finished article.

It has been obvious from the very early days of moulding that the conduction of heat from the surface of the mould to the article in the mould, that article being made of a material which was essentially a non-conductor of heat, was a most inefficient process. One of the earliest attempts made to improve matters was to preheat the pellets in an oven by the side of the press and this method is standard in a great many moulding cycles up to the present day. It does help to increase the flow of the material in the mould to a certain extent, but even in the oven method of preheating one is still unable to get heat into the centre of the pellet where it is so badly wanted.

Still trying to overcome this drawback—the lack of heat conductivity in a moulding material—another process which has been very successful in a large number of applications is the transfer process. Here the bulk of the powder is heated outside the mould proper and, when its plasticity has improved somewhat, it is forced by a plunger through a narrow gate into the mould itself and, in passing through the narrow gate, the powder does stand a chance of being heated up nearer to the desired temperature.

High-frequency Heating

It is clear that so long as reliance has to be placed on the transfer of heat through a non-conducting mass, further advance in moulding practice is severely handicapped. The new process, using high-frequency preheating, is an entirely revolutionary way of heating thermo-setting moulding materials. By this new process the whole mass is raised to the same uniform high temperature and the

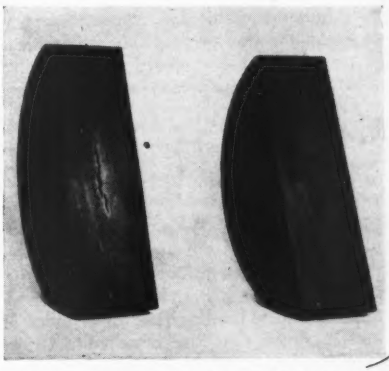

Fig. 3.—Photographs of 1-in.-thick blocks of woodflour-filled phenolic moulding material. (Left) Conventional moulding—30 minutes' oven preheat at 100 degrees C., 25 minutes' cure at 150 degrees C. and 1 ton/sq. in. (Right) Heatronic moulding—high frequency preheat at 150 degrees C., 1¼ minutes' cure at 150 degrees C. and 1 ton/sq. in.

whole mass is at the same uniform state of high plasticity before entering the mould.

This revolutionary method of heating a non-conducting material comes about in this way. When a dielectric material is placed between the plates of a condenser to which an alternating potential is applied, the material is subjected to an alternating state of stress and strain. The dielectric then holds a quantity of potential energy, which may be released or discharged in a number of different forms. The major portion of the energy released can appear as heat and the so-called " loss factor " is a measure of the amount of energy dissipated in this way.

During the growth of the radio and allied industries it was found that as higher and higher frequencies were brought into use, the standard insulating materials became less and less suitable, because they could not stand up to the increased stresses and dissipated the electrical energy in the form of heat. In fact, one of the earliest ways in which the effect of high-frequency heating on moulding materials was realized was when complaints were made about the quality of moulding materials—complaints which were only overcome by introducing new materials of lower loss characteristics. The heating of a dielectric material by alternating current was, therefore, originally a nuisance.

Mechanism of High-frequency Heating

The theory of high-frequency technique is all tied up with discussions on polar and non-polar molecules and such like complexities and it is not proposed to discuss it in detail. It is quite sufficient to know that high-frequency currents produce heat in each individual particle of a mass of material and that the mass of material becomes uniformly and homogeneously warmed up throughout its bulk, but the summarization of a few salient points might be of interest.

The molecules of the synthetic resin materials with which we are concerned are not electrically symmetrical, and if such molecules are placed in an electric field they tend to align themselves in much the same way as small magnets do in a magnetic field. In addition to this electrical asymmetry, when the molecule is placed in an electric field it tends to be distorted; that is, electrical asymmetry is induced in it.

Now, if the field potential varies rapidly, the molecules lying within the field will tend to vibrate as a whole and also tend to suffer cyclic distortion. It will be appreciated that the molecules involved in the case of moulding powders are complex and movement as a whole is not generally possible, but parts of these complex molecules can and do vibrate in

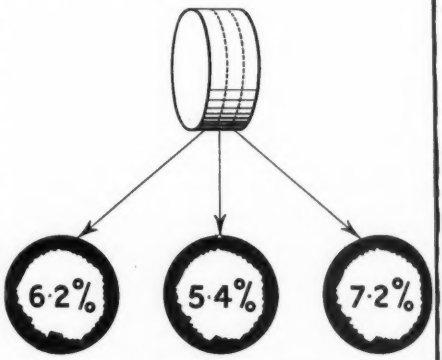

Fig. 4.—Diagram showing acetone extractions on sections of 1-in.-thick heatronic moulding.

sympathy with the variations of the field. The amount of displacement and molecular strain induced by the field—in other words, the degree of polarization—determines the value of the dielectric constant of the material. Part of the resistance to this polarization—that is, the damping effect—gives rise to the dielectric loss of the material and is responsible for the absorption of energy and, consequently, the rise in temperature. If the materials and conditions are kept constant, this tendency to vibrate depends only on the potential gradient. Therefore, provided the potential gradient throughout the material is kept uniform, the material

will heat uniformly throughout its mass.

There is clearly an essential difference between this type of heating and conventional heating by conduction. In high-frequency heating the rate of heating of each small portion of the mass depends on the value of the potential gradient through it, and therefore its rate of rise in temperature is independent of the portion next to it, so that, provided the mass and potential gradient are uniform, there will be no variation in temperature throughout the mass. No conduction or transfer of heat takes place.

The use of high-frequency or electronic

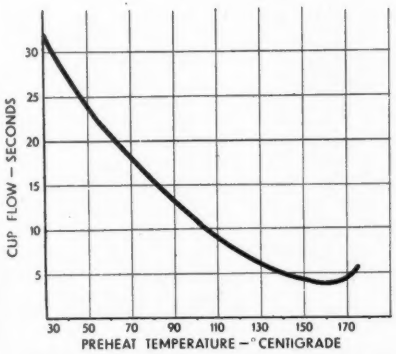

Fig. 5.—Curve showing variation of cup flow with high-frequency preheat temperature.

heating as a method of producing an increasing temperature throughout the whole mass of a material has been of rapid growth only in the past few years. It has been used for some years in medical work and for certain other specialized purposes, and it now seems somewhat surprising that it was not used commercially at an earlier date for the industrial heating of such dielectrics as moulding materials; but like many things which seem relatively simple when the problem has been solved, and one then wonders why it was not thought of before, the fact remains that the actual conception of the possibility of using high-frequency heating seems literally to have jumped out of the laboratory and become almost overnight a much-debated possibility and is now recognized as a potential tool which may revolutionize our previous conception of moulding possibilities.

Heatronic Moulding

The first announcement made in regard to the practical use of high-frequency heating for commercial moulding of the thermosetting moulding powders was contained in the paper by Meharg, published in the March, 1943, number of "Modern Plastics," the well-known American journal. The "portmanteau" name "heatronic" has been coined to cover the process of moulding using high-frequency preheating. The process has been covered by patent application both in America and in this country with the intention of making it available to the whole industry. Should the patent application issue as a patent, it will be freely available for the use of anyone and everyone in the industry without question of restriction, licence or anything else of the kind.

The word "heatronic" is not a registered mark, and it can be used freely by anyone who cares to use it. It is merely a name based on a combination of the words "heat" and "electronics," and it seems to be a useful word to describe the process covered by my talk this evening.

Method of Preheating

The actual preheating operation itself is carried out by placing a weighed quantity of moulding material either as powder in a suitable inert container, e.g., porcelain pot or other low-loss material, or as one or more preforms made in the usual pelleting machines, between two metal plates (electrodes), thus forming a condenser of which the moulding material is the dielectric.

The electrodes are coupled to a high-frequency generator and, after switching on the current, the moulding material in a short space of time becomes uniformly heated throughout its mass. The temperature rises rapidly and steadily, and continues to do so until the power is switched

off. It must be appreciated that when a preform has been heated by high frequency to about 140-150 degrees C., the curing reaction is taking place quite rapidly, and if there is any undue delay in transferring the hot charge to the mould (say, half minute), or if the temperature rises too high (say to 160-170 degrees C., which may only allow a margin of the fraction of a minute), the moulding material may harden out before it can be got into the mould. So the time cycle will need to be carefully watched. If, however, the preheating is only carried out to a lower temperature, such as 120 degrees C., then a much greater latitude is possible in the handling speed.

One important point the moulder must watch is to see that the condenser set-up is geometrically symmetrical. A uniform electric field through the dielectric is absolutely essential in order to achieve uniform heating. The plates of the condenser must be exactly parallel and the pellets or powder of uniform density and thickness. The usual pellets produced in a punching or rotary pelleting machine are satisfactory.

The one thing a moulder needs to know about the electrical characteristics of the electrodes is (a) whether one electrode is at high potential and the other at earth potential, or (b) whether both electrodes are at equal but opposite high potential. In both cases, of course, the potential is fluctuating at frequencies of the order of 5 to 50 million cycles per second, depending on the characteristics of the generating set. The heating effect in either case is exactly the same, but it makes a difference as to the method by which the temperature can be measured and, as pointed out above, the temperature reached in the preheating process must be carefully and accurately measured and controlled.

When the set is such that one electrode is at a high potential and the other at earth potential, there is only one satisfactory method of measuring the temperature. This is by inserting a thermocouple needle in the pellet at various time intervals as soon as the pellet has softened sufficiently for the needle to be inserted (about 80 degrees C.). In order to do this, the power must be switched off, the needle inserted, the temperature recorded, the needle removed, and the power switched on again. If the needle were left in the pellet it would generate a local hot-spot.

Where the two electrodes are both at high potential, the temperature of the pellet can be taken by the same method, using a thermocouple needle, but there is also another method by which direct and continuous reading of the temperature can be taken. This is done by using two pellets and placing the thermocouple between them. Being in the centre of a balanced circuit, the thermocouple is at zero potential and can safely be left in the circuit during the whole time of heating the pellets, and the temperature can be recorded continuously.

In starting up any job using high-frequency preheating, the first thing the moulder must do is to determine the best temperature to which the pellets must be preheated for the particular moulding in hand. This can only be done by trial. It is very unlikely that the moulder will be able to work with pellets at a higher temperature than 150 degrees C. and even at this temperature the pellet is curing fairly rapidly and it must be possible to transfer quickly (within, say, half a minute) from the preheating apparatus to the mould. Having once determined the particular temperature required, it is quite unnecessary to go on determining temperatures and the heating of the pellets on what is now a standardized set of conditions for this particular run of mouldings can be carried out to a fixed time schedule.

Advantages of Heatronic Process

The lecturer had pointed out that in the heatronic process the whole mass of moulding material is heated to a uniform high temperature. This leads automatically to two very important and fundamental advantages—first, the possibility of a shorter curing time; secondly, increased reliability of the moulding

material in the mould. It was proposed to deal with these two advantages separately.

Time of Cure After High-frequency Preheating

It is possible to reduce the time of cure in the mould very considerably by high-frequency preheating. Curing is almost entirely a chemical change and the speed of this change depends solely on the temperature. The curing reaction takes a definite time at any one temperature and if the whole mass of material is already at that temperature before being put into the mould, as can be the case in heatronic moulding, the curing reaction will go on uniformly throughout the mass for simply the definite period of time required to complete the cure and with little or no further heating. This, theoretically, should lead to a curing time which is independent of bulk or thickness.

Fig. 2 shows the relationship between minimum curing time and thickness for some typical moulding materials after high-frequency preheating to 150 degrees C. and then moulding at 160 degrees C. and one ton per sq. inch. The preforms were 200 grams in weight and were heated by high frequency to 150 degrees C. in a matter of two minutes. It will be seen that the curves rise only slowly; in other words, the curing time is almost independent of thickness, whereas by conventional methods of oven-preheating and moulding the curing time as shown by the curve on the left rises enormously as the thickness goes up. Roughly speaking, the annihilation of thickness tends to bring all sizes and thicknesses of mouldings down to one common moulding time. The curves show clearly that for thicknesses above ¼ in. or so, the time-saving by heatronic moulding as compared with conventional moulding becomes more advantageous the thicker the moulded article.

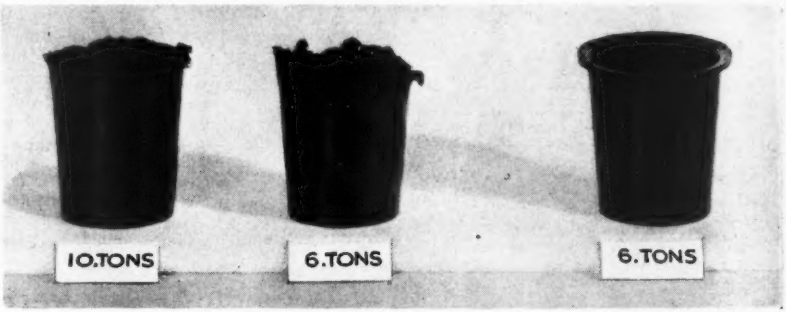

Fig. 6.—Mouldings illustrating the increased flowability obtained by high-frequency preheating.

As a direct result of the annihilation of thickness, a greater scope in design of moulding is possible, by virtue of the fact that thick sections and irregular mouldings having adjacent thick and thin sections will no longer trouble the moulder with problems of undercure and overcure and mouldings will not have to be pared down at the expense of sturdiness in order to achieve a reasonable production rate. Furthermore, the adoption of heatronic moulding can immediately increase the production rate of many moulded articles such as meter cases, door knobs, instrument panels and the like, where curing cycles of 6-10 minutes are commonly given at the present time. The output rate of any press is greatly increased and at the same

time heatronic moulding produces a better article.

Thick mouldings are avoided as far as possible in the moulding industry. Too often thick mouldings, which are apparently sound from outside appearances, are hollow or cokey and weak at the centre. Fig. 3 shows two half-mouldings, 1 in. thick, both of which were apparently, from outside appearances, sound and perfect mouldings. Moulding A was made by preheating the charge of powder in an air oven for 30 minutes at 100 degrees C., followed by a cure of 25 minutes at 150 degrees C. Moulding B is a heatronic moulding made by high-frequency preheating to 150 degrees C. in a matter of 2 minutes, followed by a cure of 1¼ minutes at 150 degrees C. It will be seen that moulding A, the conventional moulding, has a small hollow crank at the centre, while moulding B, the heatronic moulding, is solid throughout.

Fig. 4 gives the results of determining the acetone extraction of various slices of moulding B (the heatronic moulding) photographed in the preceding slide. The slide shows how the 1-in.-thick moulding was sliced into three portions and the centre of each slice taken out for acetone extraction (B.S.S.711). It will be seen that the centre section has a lower percentage of soluble matter than either of the two outer sections and, in fact, the moulding is better cured at the centre than on the outside. This is the complete reverse of present-day conventional results and demonstrates quite clearly that heatronic moulding should give 100 per cent. freedom from hidden flaws.

It is understood that in America they are using the heatronic moulding unit to produce 2½-in.-thick blocks 6 ins by 6 ins. Formerly—as they express it—" this was quite a chore " and a cure of several hours was necessary with very carefully controlled conditions, moulding the pieces from one side. These blocks are now produced in three minutes and pulled hot.

Although all heatronic mouldings are completely formed mouldings, solid throughout, and, in the words of B.S.S.771, " free from porosity, blisters, or gas pockets, and a cut section shall have a homogeneous texture on visual examination," there are other aspects of curing rate, or, rather, curing time, which must be considered. Even though a moulding is fully formed, there is often a minimum curing time; that is, a minimum time at curing temperature, below which the moulding material will not reach its maximum chemical resistance.

Mr. Dring then gave a good example of chemical resistance. He showed a set of mouldings in an alkali-resistant moulding material, consisting of ⅛-in.-thick discs which had been cut in half and heated in a solution of caustic soda (24 hrs. at 95 degrees C. in 5 per cent. solution). By conventional means (preheating for 15 mins. at 95 degrees C.) a cure of

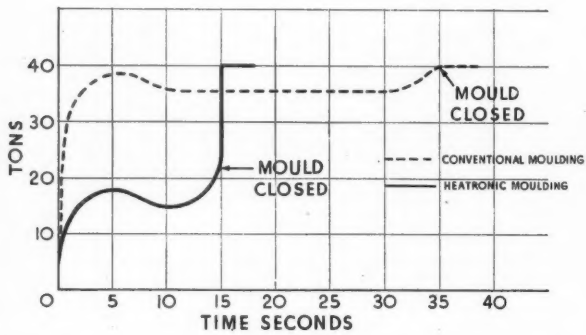

Fig. 7.—Curves showing closing time and closing pressure for (a) conventional moulding and (b) heatronic moulding.

7 mins. at 160 degrees C. was required to produce a blister-free moulding, whereas by heatronic moulding a 1-min. cure produced a solid disc, but examination of the mouldings shows that at least 3 mins.' cure is required to produce maximum alkali resistance. In the case of conventional methods, even a 5-min. cure produced a blown-up moulding of which the outer surfaces had maximum alkali resistance whilst the inside was badly attacked, and a full 7 mins.' cure by the conventional method is required to give a moulding which is at once completely formed and alkali resistant. This was an example where the thickness of the moulding so

Fig. 8.—Fire extinguisher horn and sundae dish moulded with high-frequency preheat.

increases the moulding time by the conventional method beyond the time necessary to develop maximum chemical resistance that the heatronic moulding technique is still of direct value.

Flowability After High-frequency Preheating

Another marked advantage to be gained from high-frequency preheating is the greatly increased flowability of the moulding material. Fig. 5 illustrates this point very clearly and shows the effect on the cup flow of preheating by high frequency to various temperatures. (The standard cup flow is determined by measuring the time taken to close a standard cup mould under standard pressing conditions. A powder which takes a long time to flux and fill the mould is said to be " stiff " and has a high cup flow, whilst a " soft " material has a low cup flow and readily softens and takes the shape of the mould.) The points on the curve were determined by high-frequency preheating the pellets to the required temperature and rapidly transferring the heated pellets to a portable cup flow mould. Without any preheat treatment this stiff sample of general-purpose moulding material has a cup flow of 32 secs. and becomes in effect softer and softer as the preheat temperature rises, and when preheated at 150 degrees C. becomes extremely soft indeed. The upward bend of the curve at 160 degrees C. is due to the hot pellet beginning to cure out before it gets into the mould.

Many important advantages arise from the possibility of increasing flowability. One of the most important is bound up with the problem of whether a certain moulding can be made or not. This problem occurs quite frequently in the design stage of a projected moulding, and, despite all the known tricks of technique, the limitations of available pressure, or flow of moulding material, may rule out the design as impossible.

A simple illustration of this is given in Fig. 6 (a practical demonstration of exactly the same experiment was shown at the end of the lecture). The figure shows some mouldings in a fabric-filled

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material of stiff flow made in a portable cup flow mould. The mouldings on the left, made by conventional methods, do not fully fill the mould, and it will be seen that, under the available pressure of 10 tons, this moulding is quite impossible. On the other hand, heatronic moulding so increases the flowability that the material easily fills the mould completely under a pressure of only 6 tons, giving the perfect moulding seen on the right.

Another illustration of this effect is given in Fig. 7, which shows diagrammatically some data collected whilst moulding a beaker-shaped article. The curves represent the pressures given on the pressure gauge whilst the mould was closing. The dotted-line curve gives the data for a conventional moulding with oven preheat; the continuous curve gives that for a heatronic moulding with high-frequency preheat. The press is capable of exerting a maximum pressure of 40 tons. Whereas the conventional moulding needed an average pressure of some 35 tons, operating over about 35 secs., to close the mould, the press closed in about 15 secs. at a pressure of some 20 tons after the powder had been high-frequency preheated at 120 degrees C. Obviously, this particular moulding needs only half as much pressure when made by the heatronic method, and the mould closes in less than half the time.

Fig. 8 shows two American mouldings which illustrate the advantages to be gained from heatronic moulding.

The first is a fire-extinguisher horn moulded in phenolic moulding material of medium flow. The mould is two-cavity and six preforms per cavity were used weighing 1 oz. each. The 12 preforms were given high-frequency preheating for 30 secs.; the closing time of the press is then 20 secs. and the curing time in the mould 1¼ mins. When running this job ordinarily it takes 45 secs. to close the press and 1½ mins. to cure in the mould. The use of the heatronic method has completely eliminated rejects and the uniformity of the well thickness of the piece is nearly perfect.

The second moulding is a sundae dish holder. This is made entirely from reclaim material which is allowed to be used in America for limited civilian purposes. Six tablets with a total weight of 126 grammes are used; the material is heated at 2 kilowatts for 30 secs.; loading and closing time of the mould is 6 secs. and curing time 1¾ mins. Under the usual moulding conditions the curing time is 5 mins. This job has always been a difficult one with a high percentage of rejects in standard moulding. The rejects have been eliminated with heatronic moulding.

A further direct consequence of the increased flowability obtained by high-frequency heating is that the range of jobs which any one press can tackle is considerably enlarged and an increased production rate is also possible by increasing the number of impressions on a given press.

Metal Inserts and Transfer Moulding After High-frequency Preheating

Metal or other inserts in a moulding have caused a good many headaches in the moulding industry; the problem of keeping them exactly in place whilst the moulding material is fluxing and flowing around them is often difficult. Heatronic moulding technique simplifies the problem owing to the greatly increased flowability or plasticity of the moulding material.

It was already mentioned that transfer moulding has been used as one of the ways in which the plasticity of the moulding material can be increased when using the heat-conduction method of heating the moulding material, and transfer moulding has proved of great value with mouldings containing delicate inserts. The combination of heatronic moulding and transfer moulding is even more valuable. In transfer moulding the material is placed in a heated pot from which it is forced through a narrow port into the actual mould. Before the material can move, it must receive heat from the hot chamber and become fluxed to a certain degree, and this takes some little time. Conse-

quently, transfer times can be quite high, and, because so little of the material can be softened rapidly, the pressures required to force the material through the port are often very large. If the material is previously plasticized by high-frequency preheating, transfer pressures and transfer time can be considerably decreased. Besides the reduction of transfer time and pressure, there is the additional advantage that entrainment of unfluxed particles is eliminated, so giving a more homogeneous moulding.

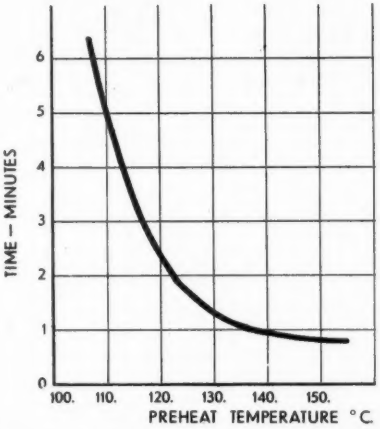

Fig. 9.—Curve showing relationship between minimum curing time and high-frequency preheat temperature for a 1-in.-thick block.

One further advantage arising out of increased flowability, although perhaps of relatively minor importance, is in connection with mould abrasion: it is probable that the use of the heatronic process will cut down mould abrasion and may even permit the use of softer metals for moulds.

Partial High-frequency Preheating

The maximum heat treatment is not always necessary or even desirable. A strong case can often be made out for partial preheating by high frequency to a relatively low temperature, say 120 degrees C., and then moulding in the usual way. The moulding material thus has increased plasticity but still requires a relatively long curing time in the mould. The desirability of such a partial high-frequency preheat depends entirely on the requirements of the particular moulding and it is very useful to be able to alter the characteristics of the moulding material in this way to suit the moulding conditions instead of having to alter the moulding conditions to suit the moulding material. Fig. 9 shows the minimum curing time of 1-in.-thick blocks of a general-purpose moulding material after high-frequency preheating to various temperatures, and even down as low as 120 degrees C. the curing time is remarkably small for such a thick section.

Figs. 10 and 11 show four American mouldings which have been moulded with such a partial preheat. The full advantage has not been taken of heatronic moulding, but it has been used to improve production and curing time, which are longer than necessary because of the moulding cycle employed. A moulder runs a number of moulds and since insert loading is involved, it is not advantageous to cut the cycle any shorter.

(1) Large connector plug in asbestos moulding material. Previous cure, standard moulding—14 minutes. Cure with heatronic moulding—8 minutes.

(2) Small connector plug in asbestos moulding material. Previous cure, standard moulding—10 minutes. Cure with heatronic moulding—5 minutes.

It will be appreciated on examining these parts that they are two of the most difficult pieces to mould and the holding of inserts in place without having the material flow over the threads is quite a problem.

(3) Small, moulded base of woodflour-filled moulding material. Previous cure, standard moulding—6 minutes. Heatronic moulding cure—3 minutes.

(4) Moulded sub-panel of fabric-filled moulding material. Previous cure, standard moulding—6 minutes. Heatronic moulding cure—3 minutes.

Improvements in Moulding Technique

Before passing on to give a little data in regard to physical properties of heatronic mouldings, the following summarizes some of the advantages to be gained from high-frequency preheating:—

1. Lower moulding pressures can be used.
2. Easier flow in the tool, cutting down number of powders required with varying flow characteristics.
3. Small presses can form larger number of impressions per press.
4. Elimination of cokey sections and the complete consolidation of a whole moulding.
5. Possibility of making more intricate shapes by compression moulding.
6. Shortening of moulding time cycles.
7. Stronger mouldings.

Physical Properties of Heatronic Mouldings

We may now turn, said the lecturer, to the technical and electrical properties of mouldings produced by high-frequency preheating. All the work so far carried out has shown that heatronic mouldings are in every respect up to the quality of ordinary mouldings and in many respects superior. The design of certain mouldings may involve awkward shapes, adjacent thick and thin sections and unconsolidated portions may lead to points of weakness—sometimes quite unavoidable. The uniformity, homogeneity, and complete solidarity of a heatronic moulding tends to eradicate or mitigate these local weaknesses.

(1) **Tensile Strength**

In Table 1 are given some figures on tensile strength of standard tensile test pieces (B.S.S.771) which are ¼ in. thick at the waist, moulded in Type G and Type HS moulding powders:—

(i) with an oven preheat of 15 minutes at 100 degrees C., and

(ii) with a high-frequency preheat to 120 degrees C., not higher because of the time required to load the pellets into the mould.

Fig. 10.—Connector plugs moulded from asbestos-filled material, with brass inserts, after high-frequency preheat.

In each case the samples were then moulded for 15 minutes at 160 degrees C. and 1½ tons per sq. in. These results show that the tensile strength is practically identical in both cases.

(2) **Impact Strength**

Table 2 gives the impact strengths of three grades of shock-resisting material, Type MS, Type MHS (a tentative designation for an intermediate grade in B.S.S. 771 with an impact strength of 0.6 ft./lb.) and Type HS, moulded by the same two methods:—

(i) With an oven preheat of 15 minutes at 100 degrees C., followed by 15 minutes in the mould, and

(ii) High-frequency preheated to 120 degrees C. and then moulded for 1½, 3 and 15 minutes.

The moulding is the standard B.S.S. 771 notched test piece 2½ ins. long by ½ in. square. Whether moulded for 1½, 3 or 15 minutes, the heatronic mouldings in Type MHS give figures 30 per cent. higher and in Type HS nearly 100 per cent. higher. These higher figures are significant of the

increased uniformity, homogeneity and solidity of thick test pieces.

(3) **Water Absorption**

In the next, Table 3, is given the water resistance of two grades of moulding materials, A and B. The test is the standard test of B.S.S. 771, in which the test specimen is a moulded disc approximately 2½ ins. diameter by ½ in. thick, one set of tests being moulded for 15 minutes without any preheat, and the other set by high-frequency preheating to 150 degrees C., followed by moulding for 1, 2 and 15 minutes. Moulding material A is a very good grade of wood-filled water-resistant phenolic moulding material; the heatronic mouldings have little more than half the water absorption of conventional mouldings. Moulding material B is a particularly interesting case. It is a moulding material using an experimental resin which happens to be rather stodgy and does not cover the woodflour at all well in the usual way; consequently the water absorption is ordinarily somewhat higher than usual, but high-frequency preheating so softens the resin that it covers the woodflour better, and the heatronic moulding steps up into the "good" class.

(4) **Electrical Properties**

Some typical figures for electrical properties are given in Table 4, using moulded discs 5 ins. in diameter and ⅛ in thick. The electric strength at 90 degrees C. and surface resistivity (dry and wet, i.e., before and after immersion in water for 24 hours) have been carried out according to the standard method in B.S.S. 771. Three sets of mouldings have been made in each grade of moulding material. The first set has not been preheated in any way, the second set has been oven preheated for 15 minutes at 100 degrees C., and the third set has been high-frequency preheated to 140 degrees C., which means a preheat for some two minutes. This high-frequency preheat has apparently "dried" the preform in this short period as effectively as a long period of drying preheat in an air oven, and the electrical figures are of the same order.

General Notes on Electrical Equipment

Mr. Dring concluded his paper with a few general recommendations, which will chiefly be of interest to electrical manufacturers supplying high-frequency machines for use by moulders.

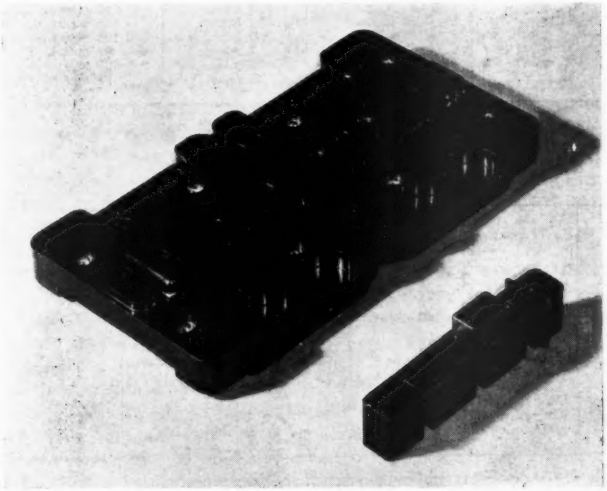

Fig. 11.—Small base and sub-panel moulded with high-frequency preheat.

(Right) Table showing impact strength of conventional mouldings and heatronic mouldings.

Table 1.

Material	Preheat	Tensile strength
Type G ..	15 mins. at 100°C. (oven)	6,360 p.s.i.
	Heatronic to 120°C.	6,750 p.s.i.
Type H.S. ..	15 mins. at 100°C. (oven)	5,440 p.s.i.
	Heatronic to 120°C.	5,500 p.s.i.

(Below) Table 2 shows impact strength of the two types of moulding.

Table 2.

Moulding	Cure	Impact Strength		
		Grade M.S.	Grade M.H.S.	Grade H.S.
Conventional	15 mins.	0.28	0.53	0.93
Conventional	15 mins.	0.28	0.47	0.87
Heatronic	1½ mins.	0.27	0.74	1.66
Heatronic	1½ mins.	0.31	0.77	1.57
Heatronic	3 mins.	0.29	0.69	1.72
Heatronic	3 mins.	0.32	0.78	1.85
Heatronic	15 mins.	0.30	0.70	1.60
Heatronic	15 mins.	0.29	0.76	1.63

Table 3.

Moulding	A		B	
	Cure	Water Absorption B.S.S.771	Cure	Water Absorption B.S.S.771
Conventional	15 mins.	109 mgms.	15 mins.	127 mgms.
Conventional	15 mins.	108 mgms.	15 mins.	156 mgms.
Conventional	15 mins.	109 mgms.	15 mins.	144 mgms.
Conventional	15 mins.	103 mgms.	15 mins.	163 mgms
Heatronic	1 min.	63 mgms.	1 min.	110 mgms.
Heatronic	1 min.	67 mgms.	1 min.	104 mgms.
Heatronic	2 mins.	65 mgms.	2 mins.	105 mgms.
Heatronic	2 mins.	63 mgms.	2 mins.	97 mgms.
Heatronic	15 mins.	82 mgms.	15 mins.	105 mgms.
Heatronic	15 mins.	78 mgms.	15 mins.	97 mgms.

Table 3 (above).—Shows water absorption of conventional and heatronic mouldings.

Table 4.

Material	Preheat	Electric strength at 90°C.	Surface resistivity (dry)	Surface resistivity (wet)	Loss factor
High dielectric grade	No preheat	135 v./mil.	1.1×10^{13}	6.8×10^{10}	—
	Conventional	170 v./mil.	1.35×10^{13}	7.1×10^{10}	—
	Heatronic	168 v./mil.	2.5×10^{13}	8.2×10^{10}	—
High dielectric moisture resistant grade	No preheat	75 v./mil.	1.45×10^{12}	1.14×10^{11}	—
	Conventional	100 v./mil.	1.0×10^{13}	4.3×10^{12}	—
	Heatronic	180 v./mil.	6.2×10^{12}	1.3×10^{12}	—
Low loss grade	No preheat	—	—	—	0.195
	Conventional	—	—	—	0.194
	Heatronic	—	—	—	0.190

Table 4.—Shows electrical properties of the two types.

(1) The equipment should be as simple, safe and foolproof as possible, as it will necessarily have to be used by relatively unskilled labour; therefore it is worth while sacrificing theoretical efficiency to a very considerable extent to achieve simplicity of operation and general robustness.

(2) Frequency should be as high as possible; this means it should be between 30 and 50 megacycles. The production of equipment operating at such frequencies with a reasonable efficiency and a high power output is not easy. Consequently, most of the equipment available at the moment operates at a frequency of approximately 10 megacycles, and provided operation at this frequency does not limit the dimensions of the load, such equipment should be quite satisfactory.

(3) The load to be heated should be an integral part of the oscillating circuit, thereby eliminating the necessity of constant and progressive tuning to remain in resonance.

(4) As pointed out in the early part of this paper, it is desirable that the heating cycle should be easily controlled by the time factor, so that for a given load and power output only a set time of heating is required. From this it follows that the cycle control system should be a system of push-button operation with time-operated knockout switches.

(5) The power output required from the high-frequency equipment obviously depends on the magnitudes of the various loads it is desired to heat and the minimum time cycles for those loads. A rough rule for calculating power required is that 100 watts will heat 100 grams of general-purpose moulding material through a temperature rise of 100 degrees C. in a time of 2½ minutes.

(6) The best size or power of the equipment has not yet been established and there are two schools of thought, one school maintaining that fairly large units should be used serving a number of presses, and the other that small units should be used serving one press only. There is a good deal to be said for both schools and it is probable that both systems will come into general use. The large set will be more efficient electrically, the valves will probably have longer life, and it will be possible to have many refinements which would be uneconomic in the smaller set. An output of 2-3 kw. would probably be required, but considerable organization will be necessary to permit operation of the equipment at maximum efficiency. With the second scheme using small sets with an output of, say, 500 watts, the necessity for organization does not arise to the same extent, since the high-frequency equipment can be regarded as an accessory of the press. The valve depreciation of such small power sets may tend to be high and this is a matter which the valve manufacturers may well consider.

(7) From the moulder's point of view there is much to be said for a system of "piping" high-frequency power from one central generator to each individual press, much as steam or gas is laid on. Such a scheme is believed to be feasible, but may be impracticable at the moment. Its solution would be a most desirable step forward and one which would give a decided fillip to heatronic moulding.

At this stage it is very little use going into detailed costs of high-frequency preheating. The process has made possible things which had previously been impossible and, from that angle alone, it is independent of economics. Many moulders already realize this and are keen to acquire high-frequency equipment for immediate and post-war jobs. High-frequency heating is not expensive; it is cheap in running costs, the only serious charges being in valve replacements and capital outlay, and when the much greater output rates and the lower mould and press charges are balanced against these items an overall economy of operation will be obtained. As one moulder put it, the problem is one which is familiar in many other instances, not "Can I afford to have a high-frequency set in my works?" but "Can I afford to be without it?"

The Welding of Thermoplastics

By G. HAIM (Arc Manufacturing Co., Ltd.)

The author discusses the history and present state of this important branch of plastics. As a result of his interest, we may expect a growth of this industry in Great Britain.

THE welding of plastics, although occasionally practised in this country, has not yet acquired the same importance as, for instance, in the U.S.A. and in Germany. As this new art will be of considerable interest in the very near future it seems to be desirable to show its potentialities.

The welding of plastics is very intimately connected with the shortage of raw materials, especially of non-ferrous metals, in Germany in the years preceding the second world war. The shortage of lead, tin and copper became so great in 1935 that the demands of the building industry and other non-essential trades could no longer be met, as all the available stocks of these metals were reserved for the armament industry.

The first call for a process comparable to the welding of metals came when the use of plastic pipes was made compulsory in the building trade. It was evident that the temperature at which such processes could be carried out would be so low, that neither the electric arc nor a flame could be used. Thermosetting substances were clearly unsuitable for welding and its use is confined to thermoplastics.

Early History of Plastic Welding

The first concrete information was given by H. Raalf[1] in his paper on the working of thermoplastic materials. He states as the main advantage of the welding process compared with the older glueing process, that bonding occurs instantaneously; the drying time, sometimes of considerable length, is unnecessary. A filler rod of P.C.U. (a grade of polyvinyl chloride) is used, the diameter of such rods being roughly $\frac{1}{8}$ in. The composition of this filler rod is approximately the same as that of the parts to be joined. The welding process is very similar to the oxyacetylene welding technique, but instead of a flame, a stream of hot air or hot gas is used. The temperature of the hot gas is approximately 250 degrees C.

Lap, butt and fillet welds can be made, but Raalf regards the joining of pipes as the most important application of the process. The diameter of extruded plastic pipes is limited, and larger sections are produced by fabrication. Sheets of P.C.U. are cut to the right dimensions and, after heating in a tunnel oven, bent to shape and welded along the longitudinal seam. They are afterwards annealed to relieve stresses and placed over a former to receive their final shape.

In cases where ordinary P.C.U. pipes cannot be used because their strength is insufficient, cast iron or steel pipes may

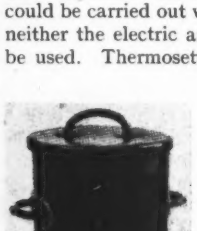

Fig. 1 (left).—Bin fabrication by welding P.V.C.

Fig. 2 (right).—Bucket, watering can and cover produced by the same process.

be lined with P.C.U. foil, glued or welded into place.

E. Roemer[2] is the next to describe the welding and glueing of plastics. He deals, however, mainly with the glueing of very thin foils of Vinidur and refers for the welding to the paper of Raalf.

Some applications of the new technique are shown by Krannich[3]. They include a dustbin (Fig. 1), a bucket and a watering can (Fig. 2), all made with P.V.C. It is obvious that many other household articles could be made in the same way, using plastics instead of metals. In such cases as these, simple forms such as sheet may be used, thus dispensing with the need for expensive moulds. The same paper also deals extensively with the application of welding to pipes and pipe connections. Fig. 3 gives a most striking illustration of a 12-in. diameter pipe bend and manifold fabricated by welding.

Modification in Heating Methods

Other details were given at the meeting of the Verband fuer Autogene Metallbearbeitung and the Deutsche Gesellschaft fuer Elektro Schweissung at their joint meeting in June, 1939, in Berlin, when Henning (the actual inventor of the process) revealed a few more details about it[4]. He explained that glueing was unsatisfactory owing to the prolonged drying time, and stated that screwed and riveted joints were undesirable because of the discontinuities caused by such joints.

The new process was developed for a number of thermoplastics all more or less on polyvinyl chloride basis. Successful tests, however, had also been carried out on Plexiglas (a material similar to Perspex). A special torch had been developed, as the use of a direct flame was out of the question. The welding gas, compressed air, nitrogen or oxygen, is pre-heated by either an open flame or by electrical means, otherwise one could say the process is very similar to gas welding.

The edges to be joined should be chamfered in order that a complete bond may be made, as owing to the low thermal

Fig. 3.—Manifold in welded P.V.C.

conductivity of the materials no penetration can take place. Filler rods may contain plasticizer, but this is not essential. Proficiency in the art should be rapidly gained by an experienced gas welder, and welds giving 70-90 per cent. of the strength of the original material can be obtained. Parts of the weld spoiled by overheating may be cut out and rewelded. The finished article is not subject to the distortion which is often experienced in metal welding.

Plastics of the P.V.C. type may be used in welded vessels to contain mineral acids and other corrosive liquids, thus effecting a saving of lead, stainless steel and other corrosion resistant metals. An enormous saving in weight is also obtained as the specific gravity of P.V.C. is about 1.4.

Henning was unable to give more detailed information at the time as the patent rights were not completely established, but a practical demonstration was given. The British patent application[5], filed in April, 1939, mentions much of the above information and gives examples of various types of joint. Tricresyl-phosphate is mentioned as a plasticizer in the filler rod, and a remarkable claim is made that oxygen is superior to hot air or nitrogen as the welding gas. Contrary to expectations, it states, no charring results from the use of oxygen.

Creation of Welding Schools

This patent application became available for inspection early in 1940, and when together with all German patent

applications it was declared void, the use of the invention became fully available in Great Britain.

Following this more and more references to the welding of plastics are found in the literature. An electrical torch is described in "Kunststoffe"[6,7] and in "Autogene Metallbearbeitung"[8] an advertisement appears introducing a training establishment to teach the new art. Three courses are advertised, one lasting two weeks, for the working and welding of Vinidur, and two one-week courses,

Fig. 4.—How the method was publicized in Germany.

one for pipelayers and fitters and the other for engineers. It is pointed out that these courses were to be of the utmost importance in view of the decisive part to be played by artificial resins as a substitute for the non-ferrous metals[9].

The inauguration of this welding school took place on December 12, 1939, and was described in "Autogene Metallbearbeitung."[10] It was pointed out that this new school was the only one of its kind in the whole world and its purpose was to make this new technique popular. At the time of the opening of the new school many hundred miles of pipes had already been installed in private houses and in the chemical industry. Such pipes were permitted by law for draining purposes and for water mains up to a pressure of about 6 atmospheres and temperatures up to 40 degrees C. With decreasing temperatures the ductility of these pipes also decreased. Special care has, therefore, to be taken by inserting expansion joints (the thermal expansion of Vinidur is six to seven times that of iron). Valves and stop cocks in Vinidur were also in use. It was possible to weld inspection windows made from Astralon into Vinidur pipes and to weld Oppanol (an artificial rubber). The visitors were then shown around the school and it was pointed out to them that all the pipes in the building, whether used for gas, hydrogen or compressed air were made of plastics and welded.

Under the slogan "Thermoplastics can be welded like Metals," much publicity was given to the process in the German literature. Fig. 4 has been taken from such an advertisement and shows an operator executing a weld in a thermoplastic material by the hot gas method[11].

Welding of Intricate Parts

By 1942 sufficient experience had been gained to apply the process to more intricate parts. H. Klant[12] describes pipeline valves which were fabricated in P.V.C. by the welding process. Originally such valves had been made by screwing and glueing, but step by step the welding process superseded the older methods and was finally adopted on a large scale. Several hundred of these valves, varying in diameter from $\frac{3}{8}$ in. to $\frac{5}{8}$ in., were working under pressures ranging up to 6 atmospheres. The labour costs of such parts are high, however, and on a large scale it would be more economical to manufacture the articles from mouldings. An excellent English abstract of this paper may be found in "Plastics."[13]

Lutz[14] describes an application of plastics to which welding is an obvious asset. Installations of piping in public-

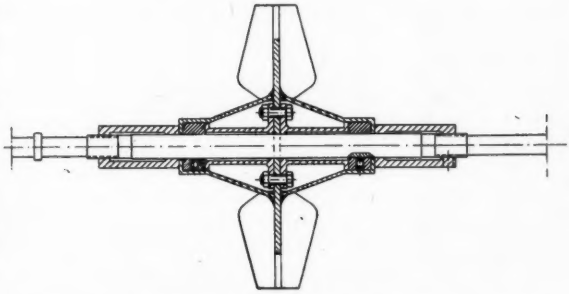

Fig. 5. — Method of welding P.V.C. impeller fan for use in corrosive atmospheres.

houses are subject to corrosive conditions and sedimentary deposits are found in tinned lead pipes and tinned copper pipes and considerable difficulty may be experienced in keeping such pipes in a clean condition. A grade of P.V.C. (Vinidur MP) has been found highly successful for this application and the use of metal pipes in public-house installations is now forbidden in Germany.

Two papers by Henning in "Kunststoffe" appear to be the standard publications on the welding of plastics. The first[15] deals with the welding of P.V.C. sheets and gives figures for the properties required of welds in plastics. The properties required of the filler rod are dealt with and a full account is given of the corrosion resistance of the weld. The second article deals with the welding of pipes—chiefly in P.V.C.—and with the applications of the process in practice. A plastic-welded scrubber for town gas is described which includes welds up to 30 ins. long[16]. One of a number of condensers mentioned had been in use for more than two years in 1941 and was giving full satisfaction. Experimental work is described which includes the welding of polymethacrylate (Plexiglas), polystyrene (Trolitul) and polyisobutylene (Oppanol O.R.G.). These papers have also been abstracted in "Plastics."[17]

A plastics fan is described in Kunststoffe[18]. The impeller of the fan is 20 ins. in diameter and works at 1,450 r.p.m. Fig. 5 shows how welding was applied to the fabrication of the impeller. Such fans are used in laboratories and other places where corrosive fumes exist.

K. Mienes[19] describes "New advances in the development and fabrication of plastics." A butt-welding machine for joining pipes is shown in Fig. 6. The ends of the pipes to be joined are held in jaws which slide in a similar manner to the jaws of butt-welding machines for metal. A heated steel plate is introduced between the ends of the pipes and both are pressed against it. When the ends of the pipes are sufficiently softened they are separated and the heater removed. The softened ends are now gently pressed together and a sound bond is secured. Mienes also shows a nitric acid plant (Fig. 7), the piping of which was fabricated in P.V.C. by welding. The use of the welding process has made possible pipes of 20 ins. diameter which have now successfully replaced ceramic pipes.

American Technique

In America the Dow Chemical Co. has developed a product allied to P.V.C. known as Saran, polyvinylidene chloride,

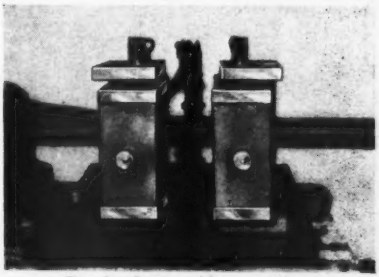

Fig. 6.—Butt-welding machine.

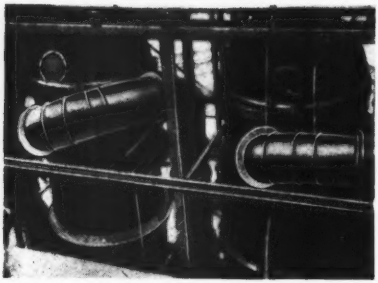

Fig. 7.—Recovery plant for nitric acid. (Note welded tubing.)

which has a narrow softening range and a sharp softening point. A process[20] is mentioned which is in essence the same as that described by Mienes.[19] The ends of the pipes to be joined are pressed on to a heated nickel plate and when softened rapidly butted together (Fig. 8). It is claimed that such welds are as strong as the original material, and that a 2-in. pipe can be welded in less than one minute. Such a process may of course be applied to other thermoplastic materials, but in general it is unlikely to prove as flexible as the hot gas process.

The Dow Chemical Co. has incorporated large welded plastic pipe assemblies in some of its works. In an article in "Chemical News"[21] details are given of a heat exchanger (Fig. 9) used on large rectifiers attached to their magnesium smelters. Voltages of the order of 15,000 are encountered in this assembly and the high insulating properties of Saran are of inestimable value.

The Heat "Sewing-Machine" Technique

The joining of pipes is by no means the only application of the welding process in the plastic industry. Using simple heating processes such as a soldering iron, two or more sheets of plastic may be joined. The German firm of Pfaff, manufacturers of sewing machines, has produced a "sewing machine" for joining thermoplastics.[22] This has an electrically heated wedge, the thin edge of which points to the gap between two rollers. The sheets to be joined pass over this wedge at a rate of 2-5 ft. per minute and then are pressed together by the rollers, giving a uniform seam of great strength, impermeable to water. Large quantities of waterproof military garments are produced by this process.

The coating of machines with heavy grease prior to storage or overseas transport, with the consequent expensive process of removing the grease after delivery, can be rendered unnecessary by a recently described American process.[23] Aircraft and other valuable parts are placed together with a bag of silica gel, in a transparent Pliofilm cover which is then sealed by means of a hand-operated seam welder (Fig. 10). To ensure the

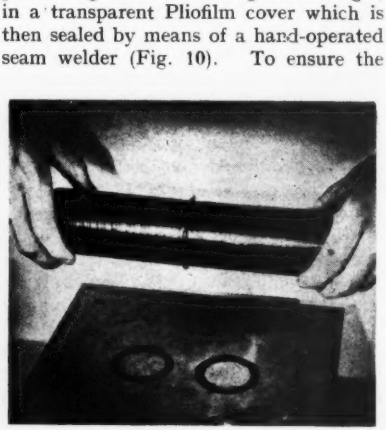

Fig. 8.—Simple method of welding Saran (polyvinylidene chloride) pipes by heating on hot plate and pressing together.

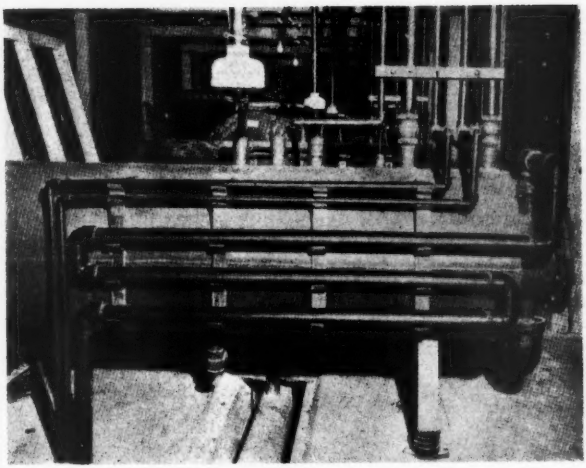

Fig. 9.—Heat exchanger in Saran piping. ("Chemical and Engineering News.")

effectiveness of the seal and the proper working of the drying agent a moisture indicator is also included in the package; any change of colour in this indicator warns the inspector of a faulty seal.

Joining processes for plastics which are allied to welding in a similar manner to the brazing process in the art of metal joining have been described.[24] Ebonite may be joined by using the hot air process with P.C.U. as a filler rod, and where this process was used for the repair of battery cases it was so successful that subsequent failures usually occurred outside the joint.

The hot gas process using a filler rod of P.C.U. or polyisobutylene has been recommended for the repair of rubber joints. Such repairs should, however, be regarded as special cases and not as general applications.

The hot gas process for the joining of thermoplastic materials has so far only been used on a laboratory scale in this country. The main obstacle to the development of hot gas welding is the lack of a suitable material. Plastic pipes and

Fig. 10.—Heat sealing of air-tight package of Pliofilm.

other products of a rigid or semi-rigid nature suitable for welding are available in the U.S.A. as Saran and in Germany as P.C.U. No corresponding product is obtainable at present in Great Britain. The appearance of such a product on the British market would undoubtedly not only lead to the widespread adoption of plastic welding, but would vastly increase the applications of plastic materials in general.

The use of high frequency electrical methods for the welding of thermoplastics will be treated in a separate paper.

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STANDARDIZED P.V.C.

STANDARDIZING P.V.C.—Since the loss of our rubber supplies to the Japanese, the Electric Cable Industry has saved large quantities of rubber by substituting polyvinyl chloride coverings. It is calculated that these savings already amount to some thousands of tons a year.

Owing to this increasing use of P.V.C. compounds for cable-making purposes, there has arisen a heavy demand for certain compounding ingredients, and it is, therefore, necessary to exercise the most stringent control over their use.

To achieve this, the Plastics Control and the Cable Planning Organization of the Ministry of Supply have decided to standardize polyvinyl chloride compounds for general and specialized cable manufacture on and after December 15, 1943. The advantages of this scheme will be two-fold; first, the reservation of essential materials, and, secondly, a guarantee to purchasers that polyvinyl chloride cables to any specification will be made from compounds of the standard required, regardless of the source of manufacture.

The Future of Plastics *(Contd.)*

Notes on the Trends of the Plastics Industry, Some of which Formed the Basis of a Talk Before the Southern Section of the Institute of the Plastics Industry on November 17, 1943, in Southampton

By M. D. CURWEN, Editor of "Plastics"

IN the first part of this talk I have tried to indicate how important it is for the future existence of the plastics industry to peep into the raw material store cupboard to make sure it isn't bare, for in this world, where most of us believe in the theory of the conservation of energy, we cannot eat our cake and still have it. The problem should be tackled quickly lest so many of our beautiful ideas be brought to nought through lack of tools.

These new ideas proceed apace without regard to raw material considerations, but before we consider their trend it may be as well to discuss the condition of research as it exists in this country.

Industrial Research

As a nation we do not like scientists, and have a distrust of too much brain-power, whether it is shown by politician, chemist or philosopher. It is also interesting to remember that it was Roger Bacon, an Englishman, who first insisted on the importance of continued experimental verification.

There is thus an innate distrust of new things and new ideas, a refusal to examine something new unless somebody else has already tried it and found it not wanting.

Concurrently, there is no understanding of the work of the scientist and, therefore, no understanding of the meaning and importance of long-term research. The financiers and industrialists are quite willing to put down money, and lots of it, for the production of goods already made in an exactly similar way in a hundred other factories because they know, with proper organization, they can get what they call adequate returns immediately, but they will put little into a new process which does not produce dividends so rapidly. Still less would they consider the financing of research with no apparent promise at a very much later date. As an instance of a wider outlook, I should like to read you a letter that appeared in a recent issue of "Chemistry and Industry":—

SIR,—In a recent issue you referred to Sir Harold Hartley's advocacy of the basic importance of scientific research to the industrial future of this country and noted, by way of example, that Langmuir's discovery of the gas-filled lamp is estimated to have effected an annual saving of £50,000,000 to this country. In these days, when the question of the organization and extension of research is so much discussed, it may perhaps be well to remind ourselves of the intellectual atmosphere in which Langmuir found it possible to carry out his great work. This may best be understood by the following quotation from his own writings:—

"During these first few years, whilst I was having such a good time satisfying my curiosity and publishing scientific papers on chemical reactions at low pressures, I frequently wondered whether it was fair that I should spend my whole time in an industrial organization on such purely scientific work, for I confess I didn't see what applications could be made of it, nor did I even have any applications in mind. Several times I talked the matter over with Doctor Whitney,* saying that I could not tell where this work was going to lead us. He replied that it was not necessary, as far as he was concerned, that it should lead anywhere. He would like to see me continue working along any fundamental lines that would give us more information in regard to the phenomena taking place in incandescent lamps, and I should feel myself perfectly free to go ahead on any such lines that seemed of interest to me. For nearly three

* Director of the research laboratories of the American General Electric Co.

years I worked in this way with several assistants before any real application was made of any of my work. In adopting this broad-minded attitude Doctor Whitney showed himself to be a real pioneer in the new type of modern industrial research.

Pure research work in this country has always been of a very high order. Industrial research on the other hand is not and has never been, for reasons already hinted at, a bright spot in our land. Money is not spent on it and, as a whole, the industrialist has been content to buy foreign processes or to work foreign ideas under licence. The same waste of intellect exists in the use of scientific workers who often become mere routine controllers of processes or spend their lives analysing competitive products so that they may be copied. To use scientific workers for original work seems to be a waste of valuable time to this type of industrialist.

One thing is certain; during the past 50 years or more the story of industrial research has been a sorry one. One thing more certain than any other is that our future industrial life will depend on it. At long last the country is awakening to this fact, and we are assured that more money will be devoted to it. But although we hear that the Parliamentary and Scientific Committee has recommended the spending of £2,000,000 a year on university buildings and plant and the British Coal Utilization Research Association is going to spend £250,000 a year on coal research, yet the real work must be done in the factories individually and collectively.

Our industrial leaders must be taught the meaning of long-term research, and that although it brings results it is a costly business. It used to be said that a good chemist could make do with a bit of glass tube and a ball of string. There was and is still a good bit of truth in this, but to-day he must also have a £5,000 electron microscope to play with. While it may be too great an exaggeration to judge a country's industrial future by the number of electron microscopes in it, yet I believe this apparatus will solve many of the plastics problems before us. Perhaps our most urgent need is to know what the big molecules really look like. Already I hear that Goodyears of the U.S.A., have found, by means of the new apparatus, an important difference between the configurations of synthetic and natural rubber molecules.

It is noteworthy that nearly all the money spent on research on plastics is carried out by the synthetic resin or polymer-producing concerns, and to a somewhat lesser extent by the electrical industry. This not only includes research on new materials, which is obviously their province, but also on new applications and new methods of employment. As a whole, the moulding industry is quite content to accept new raw materials and new methods without offering any help. There seems no desire to plan a scheme of research on a subject originated by the moulding section. We believe that the new process of moulding using high frequency received no consideration until it was a fait accompli worked on and brought to a successful issue by workers outside the moulding industry.

We must be prepared to spend money if we are to continue our industrial life. Even the F.B.I. has announced that it considers that 1 per cent. of profits should go to industrial research. This is most encouraging, for it is a figure I have long had in mind as being suitable. It would add up to a vast sum and provide adequate resources for work that cannot but produce good results. Incidentally, it would probably be necessary to train the future leaders of industrial research in a manner analogous to the training of generals in Staff Colleges. I have no doubt that a special course would be arranged to teach them not to be afraid of spending a lot of money and how to spend it well. We have to get over certain aspects of tradition.

I cannot help at this point referring to one matter that rather confuses the issue. Most of my life I have railed at industry in this country as being so much behind the rest of the world, especially Germany and the United States. Yet the old

IMITATIONS

and PLASTICS

It is a pity that when new materials come along there is always somebody who wants to make them look what they're not. You couldn't have anything much more satisfactory than the smooth finish and beautiful colour of many Plastic articles yet so often have there been attempts to make them look like walnut, mahogany, marble, or some other natural material. Some BEETLE *mouldings have been described as "imitation ivory" simply because they are ivory in colour and are smooth and lustrous—you might just as well call anything black, "imitation jet."*

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country goes fairly smoothly on its way, and in time of war suddenly bursts its traditional bonds, produces, after a few halting steps, a miracle of organization and a spate of brilliant ideas while maintaining its superbly high standard of manipulative and mechanical skill that astonishes the world. This astounding paradox may appear to defeat the argument for scientific endeavour, but I prefer to say that with the aid of scientific and industrial research we could take first place in world's trade and industry.

It has already been pointed out that by intensive research new plastics are possible by the utilization of natural materials such as proteins in bones, skins, hair and silk, of starch, etc.

What completely new synthetic types there will be is more difficult to foretell. We have been promised new individuals of the nylon series for since nylon is made from dibasic acids and amino compounds the number of nylons possible is extremely great. Not all are suitable either for filament making or moulding, but it is obvious that we shall have a large selection. For this country it is essential to realize that certain dibasic acids and the amino compounds necessary can be made from coal, that a new industry making the new series of intermediates becomes possible and that it will be an offshoot of the intermediates or dyestuffs industry, already very strong in Great Britain. Intensive research and intelligent planning can bring a host of intermediates at reasonable cost.

While on the subject of raw materials or, rather, intermediates, it would seem not outside the bounds of possibility for research to make more readily available and cheaper those types of phenols that have been too rare to come into general use. Of these resorcinol and certain derivatives of phenol may yet become of industrial importance for resin manufacture. It is too much to expect that the interesting and valuable phenols made from wood-tar will ever prove important for resin making, although they are eminently suitable for some purposes, since wood distillation is a dead industry except as a means for producing charcoal. This is a great pity, for it is a possible source not only of phenols but also of methyl alcohol, originally the only raw material for making formaldehyde and of acetic acid, acetone and acetic anhydride, all very important basic chemicals for our industry. Nowadays all these are made synthetically in much larger quantities than they could ever be from wood. It might be possible to resuscitate this industry, using sawdust.

High-strength Resins

While on the subject of phenolics, it appears that no research has ever been carried out or even conceived on the improvement in strength of the resin itself. All attempts at producing strong mouldings have made use of the incorporation of fillers. Yet there is an enormous gap between the maximum theoretical strength of a cured resin, which should be nearly 2,500 tons per sq. in., and the practical results we get—only 5 tons per sq. in. The difficulty lies in the present inability to get the reactive points in the molecules close enough together, so that in the finished moulding only very few links hold the groups together. How far we can narrow this gap, and how, we cannot tell, but one interesting suggestion recently made to me is that it might be reduced by the adoption of an adsorption type of technique where enormous surfaces of an adsorbent may produce the desired catalytic effect.

In the meantime I have considerable pleasure in reporting that a new phenolic moulding powder is now available for making mouldings with a very high shock-resisting power, of the order of 2-3 ft./lb., that is about 10 to 15 times better than the ordinary wood-filled grade. This result has been brought about by the use of special string suitably impregnated as the filler and opens up fields in industry especially in engineering which had never previously been entered. We are, by its means, rapidly approaching the time when we can call mouldings of this type not only "non-brittle" but "unbreakable."

THE PROMISE OF THE FUTURE

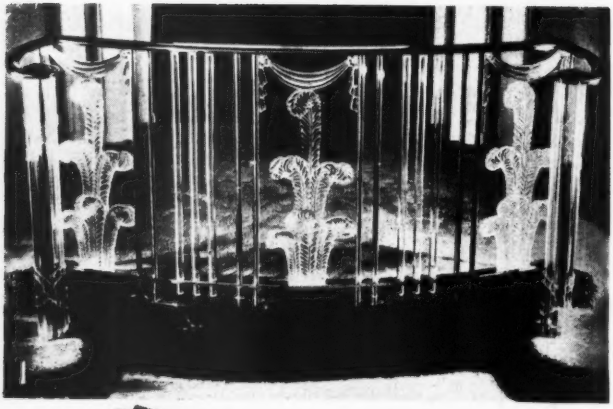


Fig. 1. — Methacrylate resin and Art.

Fig. 2.—An experimental connecting rod of re-inforced plastics.

Fig. 3.—Curved extruded tubes for domestic and industrial purposes.

Fig. 4.—Curious result of subjecting cellulose acetate to H.F. current. S. gravity is about 0.1. Note formation of "cross-members" giving great strength.

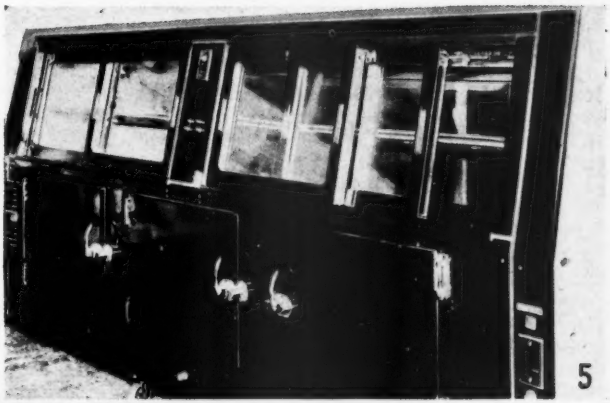


Fig. 5. — An American refrigerator fitted with plastic window frames, forming integral part of construction.

Fig. 6. — Design and Plastics. An American conception of the future electrically operated typewriter.

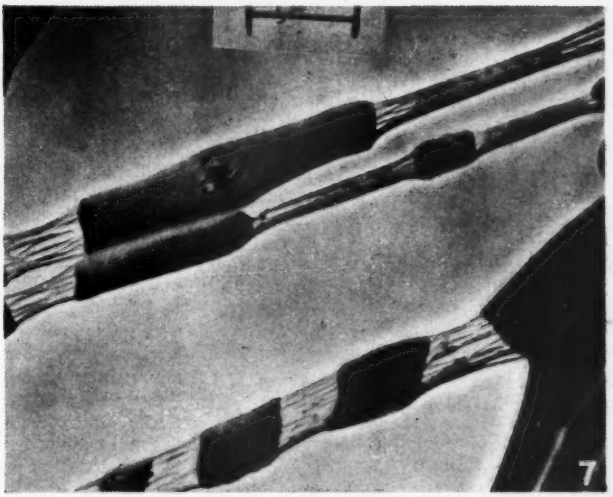


Fig. 7. — Our knowledge of the shape of plastic molecules is increasing through the electron microscope. Unit shown at top is 1 μ. The photograph shows polystyrene with "black" carbon aggregations.

While on the subject of strengths you will all have noted that many extruded filaments, e.g., the nylon and some vinyl types, show greatly enhanced strength on stretching because of molecule orientation, the strength often reaching that of mild steel. In the moulded form, and nylon will be used so in many post-war applications, the tensile strength is, however, not exceptionally great, because of absence of orientation. One would like to pose the question, is not an orientation possible in the hot fluid state?

A great need in the thermoplastic field is the production of better plasticizers, a vast number of which, up to now, have been produced but only a few have been satisfactory. Most of the work has been of a "cookery chemistry" nature.

Heat-resisting Plastics

After increased strength one of the most desired of improvements in plastics is increased resistance to heat. To-date the maximum temperature at which the most resistant can be used is under 200 degrees C., the plastic being admixed for the purpose with mineral matter such as asbestos.

Quite recently an interesting series of resinous materials, in which the carbon is partially replaced by silicon which obviously confers heat resistance, has been examined by an electrical concern. The resins are known as silicones and are stated to resist temperatures up to 250 degrees C., but authoritative information is still lacking. Compounds in which silicon replaces carbon in the molecule are by no means new. One such material, silicon ester, $Si(OC_2H_5)_2$, has been on the market for over 12 years, as a paint, waterproofing and stone-treating medium, and was sold as a water-white liquid. It would be interesting to incorporate this in an alcohol soluble phenolic resin to try to confer increased heat resistance. The silicon ester on exposure to air or heat deposits silica.

New Moulding Methods

New methods for utilizing plastics are growing apace, and in some directions there appears possible a considerable revolution in technique.

One of the most desirable of attainments is obviously that of the production of cheap moulds. The possibility of the elimination of so much tool work is being sought by examination of methods of hobbing, casting and electro-deposition or spraying of metals to form a skin which could then be peeled off the master and supported on a metal base.

High-frequency Treatment

Of first-class importance is the introduction of high-frequency moulding which promises to be the biggest step forward since moulding was first practised. Mr. Dring's excellent paper before the Institute of the Plastics Industry, published elsewhere in this issue, shows how valuable the method is, not only from an economic time-saving point of view, but also because of high quality.

The use of high frequency as a means of curing or heating is also being perfected for the treatment of resin-bonded plywood, a method which may yet have its repercussions on the aircraft industry. Finally, the welding of thermoplastics by the same means is being perfected in this country and abroad, especially for the joining of sheets, which means that the waterproof clothing and similar industries will thereby benefit. It must be noted that since high-frequency heating is affected by dielectric losses, the very superior dielectrics such as polystyrene and polythene cannot be so welded.

The welding of thermoplastics brings to mind the rapid progress made by yet another method, the heating of the thermoplastic and welding by simple pressure or by the use of welding rods made of thermoplastic. Mr. Haim's notes on this subject, elsewhere in this issue, are a valuable contribution to our knowledge on it and gives ample promise of future developments of special value to the chemical industry, but also of importance to domestic and industrial piping, etc.

The mention of domestic piping serves to introduce the progress made in extrusion. The first tubing extruded from

phenolic resins and made on an industrial scale in this country was used as ink rollers on a well-known duplicator machine. To-day tubes are available with bends and will find application not only for special domestic purposes, but also for "speaking" and vacuum conveyor tubes.

Adhesives

The past few years have been noteworthy for the production of a wide range of synthetic adhesives which have given a tremendous impetus to plywood and other wood structures in the aircraft and boat-building industries.

In spite of their undoubted importance, the moulding industry is still asking for a new glue or cement to join two pieces of cured resin together. This is an extremely difficult job, but the advent of such a material would probably considerably cheapen mouldings; there are undoubtedly cases where a complicated design could be carried out more cheaply using two or more simple moulds, the mouldings from which could then be cemented together. There are now synthetic glues which claim to be quite satisfactory for the purpose.

Blowing of Plastics

One of the oldest of plastic processes, that of blowing hot air between two sheets of celluloid and thus cementing them to form a hollow, ball-shaped article, is in process of being adapted to modern methods and modern plastics. Such a technique, refined to eliminate joining lines, that is by adopting the glass-blowing technique, would ensure new markets for fancy goods and domestic ware, and even in industry. Bottles to contain hydrochloric or nitric acid would be a god-send to laboratories and many small works, while cistern balls and similar floats of seamless structure would be welcome.

Insulation

I have often stated that I regard plastics as a logical material for making low-temperature insulating structures, for, unlike normal insulating materials which generally need superstructures to hold them in position, all plastics can be made rigid and, at the same time, strong enough to support themselves and all, of course, are bad heat conductors. A moulded refrigerator door of solid plastic is not a fully efficient insulator, but it is better than a metal one. A great advance is now being made with expanded plastics in which air or gas cells, the great proportion of which are isolated one from the other, are introduced into the mass. Thus a structure $\frac{1}{2}$ in. or 1 in. thick, extremely light yet sufficiently strong, can be made. Cellulose acetate has been thus treated, but the best results appear to have been made with certain vinyl plastics which give an amazingly strong structure for a very cellular material. The outside surface is made smooth and non-cellular and can be made to adhere permanently to wood veneers and to metal sheet.

A curious-looking job is the egg-shaped expanded plastic shown in the photographs. This has been produced by the action of high-frequency heat on cellulose acetate. A cellular structure has resulted, but it is amazingly strong.

On the subject of design I cannot say anything because I am ignorant about this fascinating but difficult subject. That much of the future of plastics depends on it is obvious and, as an example of what will be done, I reproduce a picture of an American design for an electrical typewriter, most of which is to be of plastics. There is this to note about it. Being an electrical job, there must be plastics for that part of it. Again, being an electrical job, the contacts and moving mechanisms are considerably reduced in length so that a "streamline" design is possible and makes the use of plastics both proper and pleasing.

Enough has been said to indicate that although we shall never be living in a foolish paradise where our wings are of transparent acetate and our harp strings of nylon, yet there is much to look forward to on this earth, as a more efficient, cleaner and more amusing place than it ever has been.

World's Industry Employs Plastics

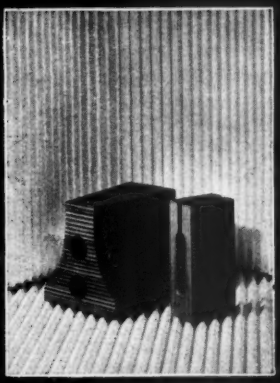
MOTORS

Marvinol, a vinyl-type plastic produced by the Glenn L. Martin Co., Baltimore, possesses rubberlike qualities of a peculiar type, such that it is claimed that the material is in a position to bridge many gaps hitherto beyond the capacity of the so-called synthetic rubbers. **Economic production of synthetic rubber tyres** by the combined efforts of U.S.A. Chemical and Rubber Industries is reviewed by E. L. Warner, Junr., in "Automotive and Aviation Industries," 1943/89/26. The account surveys very comprehensively durability tests on tyre sets consisting either partly or wholly of synthetic rubber, together with synthetic fibre. It is interesting to note that, so far, tyres of natural rubber, on the whole, give greater durability than those of the synthetic materials. **New line of small panel instruments** of internal-pivot construction for aircraft, automobile and general industrial use has been developed by the General Electric Co. The instruments are provided with dustproof and moisture-resisting cases in brass or moulded Textolite ("Automotive and Aviation Industries," 1943/89/44). **Polyvinyl butyral** will shortly be available in U.S.A. for safety glass for civilian uses. Allocations will be limited and based on previous use of this plastic in war emergency fields by the applicants. **Acrylic monomer and acrylic resins** generally have been included in the products covered by order M-154, thus bringing this group into line with the other thermoplastics, the use of which for general purposes is strictly limited in U.S.A., allocations being reserved primarily for military uses.

ELECTRICAL

Compounding of Buna S has recently been made the subject of investigations by Selker Scott and McPherson ("Journal of Research," National Bureau of Standards, R.P. 1554). Buna S, a co-polymer of butadyene and styrene, is, without fillers, possessed of good electrical properties, being, however, mechanically weak. Although carbon black develops mechanical strength, it does so at the expense of the electrical characteristics. The use of gilsonite in place of carbon black for Buna S has recently been examined. It is found that the insulating properties of the material are suitable for telephone cables and the like. **New miniature blower** weighing only 2 oz. and 2¾ ins. in height, intended for cooling electrical control equipment and for furnishing circulated air in restricted spaces is described in "Product Engineering," 1943/14/699. The design was made possible by the use of high impact strength phenolic plastic for the housing and a moulded phenolic resin blank for the backing plate, on which is mounted the motor. The blower is furnished with a cadmium-plated steel rotor, operating at 3,000 r.p.m., and the blower delivers 15 cubic ft. per minute. In the same issue of the journal just cited a **double-injection moulding process** is described, as used for the moulding of a counter wheel in a black thermoplastic. Cut-outs are arranged in the first moulding, these being filled with white numbers during the second shot. Application of the principle for the prevention of shrinkage cracks in complex mouldings is also suggested, to avoid difficulty of varying sections.

PERMALI



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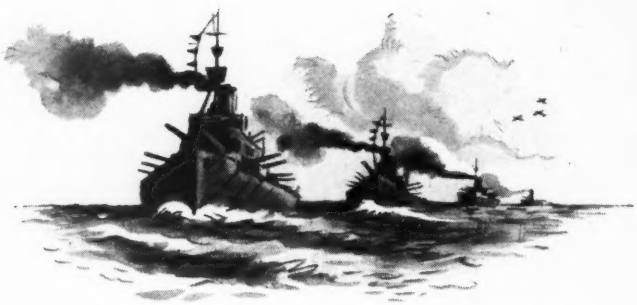

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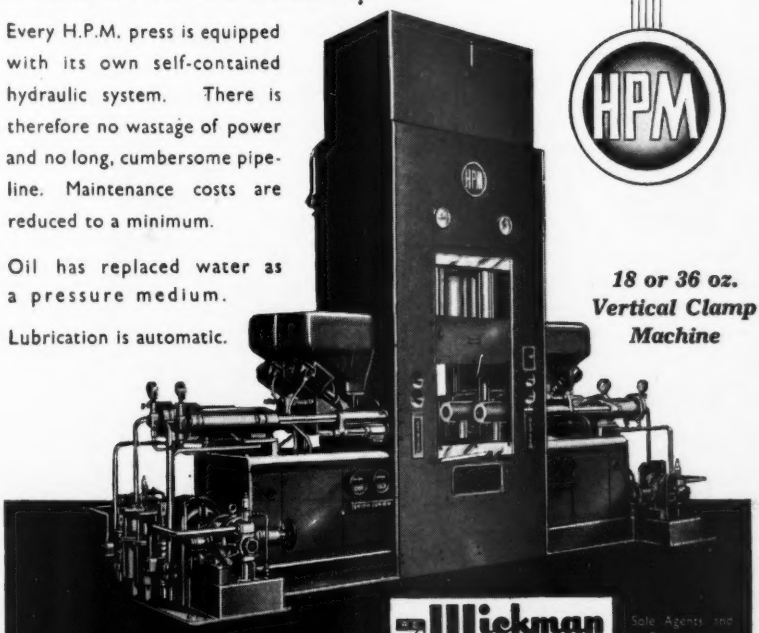

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GENERAL ENGINEERING

Machining and finishing of Tenite employs methods different from those required for many other plastic materials. Tenite is, however, tough, and must be sawn, turned, punched and scraped in accordance with this quality. In " The Tool Engineer," 1943/12/85, the production facts and tooling problems are comprehensively reviewed. Incidentally, the journal referred to is the official publication of the American Society of Tool Engineers which for some time has paid special attention to the more intricate problems of plastic moulding and machining. **Neoprene damping pads** are used by the Savway Industries, 4875E, Eight Mile Road, Detroit, on their new multi-purpose internal grinder. The bed of this machine is similar to a thick surface plate and consists of a normalized alloy iron casting; between this and the steel base of the machine the neoprene pads are inserted, eliminating metal-to-metal contact and preventing transmission of floor vibration to the plant. **New cutting technique, known as friction cutting,** has been found extremely useful for cutting not only aluminium and steel, but also what is described as a new and very tough laminated plastic, the nature of which is not disclosed. The friction-cutting technique employs a tool operating at a peripheral speed of 12,000 ft./min., the tool consisting of a high carbon steel circular saw, similar to that used for wood, and provided with 8-14 teeth per inch. On the plastic material referred to a carbide-tipped saw failed after cutting through 18 ins. of 1½-in. thick material. By the friction method, a perfect cut was made without any damage to the saw. Glass tubes and armour-plate can also be cut by the same method, the latter at a rate of 14 ins. per minute. The system does not work satisfactorily in the case of soft rubber (Machine Design," 1943/15/118).

MISCELLANEOUS

Mechanical properties of Plexiglas have been compiled in a new technical booklet issued by the American Röhm and Haas Co. Particularly noteworthy are the details of test methods and test results summarized in the work. **U.S. Government specifications for plywood and synthetic adhesives** are catalogued in a bulletin recently issued by Resinous Products and Chemical Co. **Recent English publication on plywood** by Linn and Wood has been followed by an American edition of the same work, published by the Chemical Publishing Co. Inc., of Brooklyn. The book is well illustrated, shows constructional uses of plywood and embodies extensive appendices and glossaries. **Quicker setting at lower temperatures** is achieved for 1421 Durez liquid resin by the use of accelerator 7422. The accelerator is acidic in nature and is added to the melt before pouring, the whole being allowed to stand 15-30 minutes to permit discharge of bubbles. With the accelerator small castings require 8 hours at 160 degrees F. to effect curing. **Plastics and other non-metallic structural materials** are listed in a handy directory published in " Machine Design " for October, 1943. Plastics and other non-metallics generally, a systematic presentation of various plastic types, producers and moulders are comprehensively covered. **In the jet-moulding head for thermosetting plastics** developed by Plastic Processes Inc. and noted in " Machine Design," 1943/15/118, the head is designed to fit a standard injection-moulding machine for thermoplastics. Extremely dense mouldings free from all porosity are said to be produced, due possibly to the high temperatures employed. The plastic, when passing through the injection nozzle, is flash-heated to temperatures between 400-1,200 degrees F., depending on the nature of the plastic and the moulding.

PLASTICS AND PAINT

By D. H. HEWITT, M.A., A.I.C.

Berger Plastics Developments, Ltd.

The author records the implications of plastics on the paint industry, the advantages and disadvantages of synthetic resins, and implies the need for close technical co-operation between both industries.

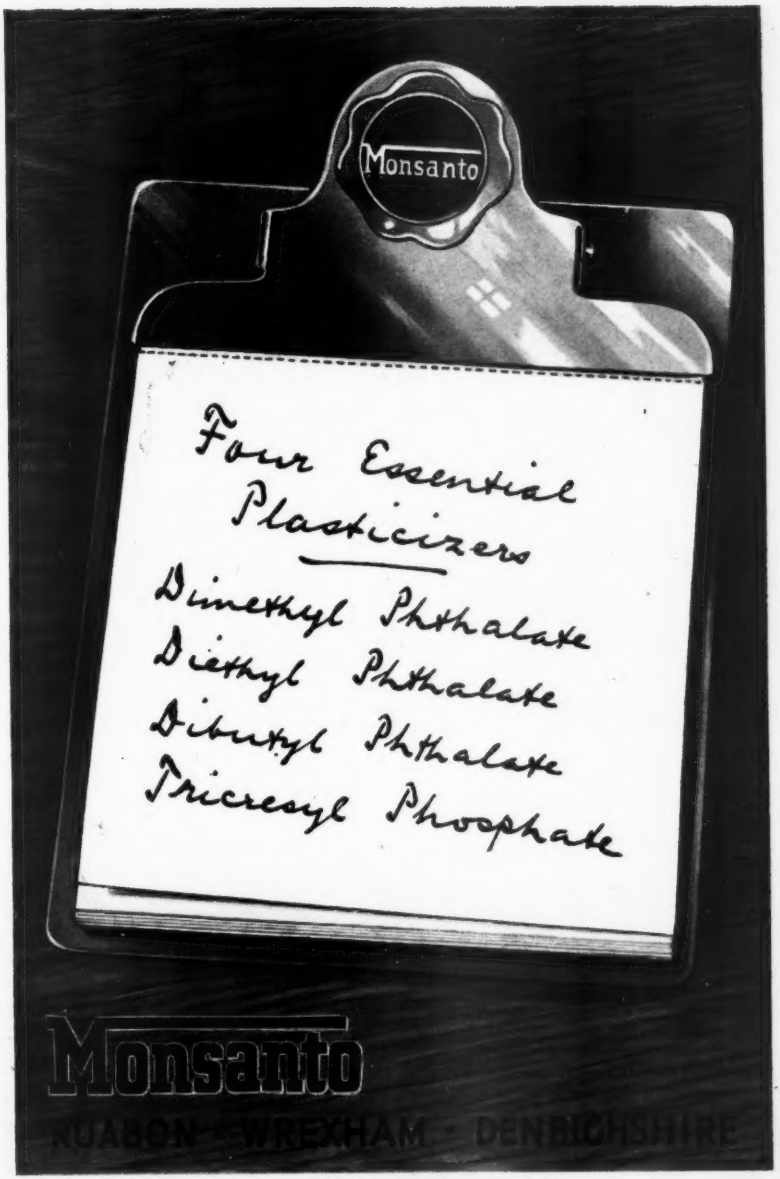
A VERY great deal of quasi-prophetic writing, especially in the more irresponsible sections of the Press, has given rise to an unfortunate popular impression that we are heading for an age in which plastics will predominate at least as constructional and fabricating materials to the wholesale exclusion of more familiar types.

The inherent dangers of this tendency have been fully recognized by the plastics industry, and its technical and commercial leaders are doing everything possible to restore a normal perspective by means of articles, speeches and advertisements. They have very rightly pointed, inter alia, to the comparative expense of a number of plastic raw materials and to the practical difficulties of fabrication as ponderable factors in determining the limits within which plastics may be expected to find major application. At the same time, and with equal wisdom, they point to the wide range of plastic bodies possessing unique properties which are finding new, rather than substitute, uses in a great variety of fields.

Among the more erratic statements of the sort mentioned in the opening paragraph may be counted those which claimed that the advent of the Plastic Age would prove to coincide with the eclipse of the paint industry! The futility of such suggestions is patent to all who not only read the commercial history of the past century, which shows that each major innovation, whilst affecting very greatly the established position of similar existing processes, invariably acts also as a spur to bring such processes to a more advanced stage of development than heretofore.

On the commercial side the impact of plastics upon paint in this country has hitherto been small. From a technical standpoint the situation is quite the reverse.[1] Paint chemists have been following with great care the development of new plastic raw materials and studying the possible application to surface coating technology of the more established types, of which supplies may be expected to become available in the post-war world.[2] It is a truism that a good many of the main plastic types in their original states of development have not been entirely suitable for paint manufacture. Their particular properties have found immediate outlets for them in other directions, especially those in which unique performance has outweighed the factor of relatively high original cost. As increasing raw material supplies have reduced prices, adaptation for use in surface coatings has followed. To recall this trend it is only necessary to point to the gaps between the first production of Bakelite and that of the first oil soluble phenolic resins and that between the introduction of rubber and chlorinated rubber. The case of alkyd resins is an exception in that the most important outlet has, in fact, been for use in coating compositions.

Of the two classes of polymers this trend has been most marked in the case of the non-convertible or so-called long-chain type, the most usual commercial representatives of which are characterized by high mean molecular weight, with consequent poor solubility in the usual paint solvents and unsatisfactory application by brush or spray. Unique moulding and extruding properties have led to their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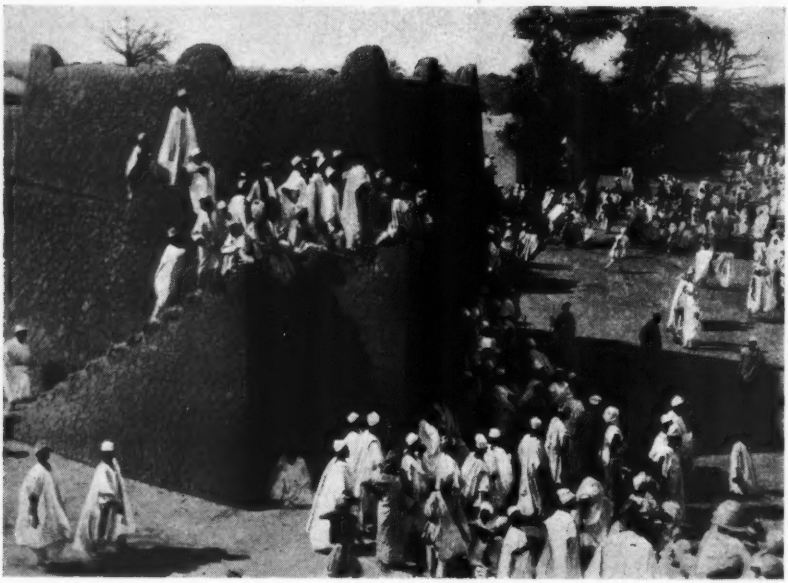

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NIGERIA

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widespread use in the formation of shapes and threads, and their outstanding physical properties have in many cases found application in electrical insulation. It has been a source of disappointment that the major technical advances in this class of resin have not as yet led, except in the case of cellulose derivatives, to any major developments in the field of paints.

There are, however, many features of plastics in which the discerning eye may see a challenge to the paint industry. The main functions of paint are protectection from chemical attack (including corrosion), coloration (decoration and camouflage) and insulation (as from heat or electricity), and it is interesting to consider the direct and implied impact of plastics on each of these spheres where paint is acknowledged to have held paramount place heretofore.

Protection from Chemical Attack (Including Corrosion)

It is immediately obvious that plastic articles themselves are not liable to chemical attack to the same degree as metals and will consequently need less protection.

There are, indeed, many fields, such as the linings of chemical plant, where plastic compositions, particularly of the thermo-hardening type, can be used to greater advantage than metals, to which they may be applied as linings. Where plastic bodies replace metal a market for paint is lost.

On the other hand, the performance of unprotected plastic bodies, such as the laminates or bonded plywood on outside exposure, seems to be largely a matter of conjecture, and very few published figures are available. It is reasonable to presume that where convertible resins are considered, providing the weight ratio of filler or base (in laminates) is reasonably low, durability may be excellent, but the behaviour of non-convertible resins may be quite different.

It will be agreed that the general order of resistance to chemical attack in the case of plastic bodies is high, and that it represents a challenge to the paint industry to improve immeasurably the performance of its coatings.

Coloration

Here again it is immediately obvious that plastic bodies may themselves be satisfactorily coloured, and that at first sight this fact denies any place for paint. It is interesting to note in parenthesis that coloured plastics, like some paints, comprise essentially a pigment and a filler in intimate relation to a resinous binder, and that those firms who have experience in the latter may be at a distinct advantage when it comes to handling this aspect of the former. The relationships between pigments and the various types of plastics have by no means been fully investigated, and the plastic worker will still be very much at the mercy of the unco-ordinated recommendations of pigment and resin supplies until a literature grows up similar to that which relates to rubber.

There is, however, one aspect of the use of paint for decoration which must not be overlooked. That is its flexibility. In the case of house decoration it has become habitual to change the colour scheme when repainting is carried out every two or three years. No little satisfaction is derived by millions at their own efforts at distempering and painting, and there is no doubt that paint holds an unassailable position in this field whether the constructional materials under consideration be plastic or no. A possible exception may be the use of plastic panels in living rooms and possibly round halls and stairways where wood is now customary; this would obviate the need for varnishing.

Weight is given to these considerations by reaction to the extensive employment of so-called plastic paint for interior decoration over the past 20 years. Such textured finishes which require expert preparation are for all practical purposes permanent, but it is found that even with careful cleaning they rapidly become tawdry in appearance. This type of paint derives its name from its ability to be textured before setting hard to its final state, and is characterized by a high con-

tent of pigments and extenders in a hard-drying vehicle. A great variety of treatment during hardening may be combined with after treatment of the hard film.[3]

In recent years the consumption of paint in decorating manufactured articles has risen very steeply, and a considerable technology has grown round the finishing of cars, aeroplanes, refrigerators and the like. The production of such articles or their parts from plastics is not likely to preclude the use of paint as a finishing coat, but is more likely to present a new type of finishing problem to the paint industry, namely, that of satisfactory adhesion to plastic surfaces. On the other hand, such replacement of wooden parts and articles by moulded products, as has occurred in facia boards for cars, will certainly militate against the increasing use of paint for industrial purposes. A long list of such examples might even now be enumerated.

Insulation

Although resinous materials of the silicone and polyvinyl types are likely to provide considerable advances in the technique of heat and electrical insulation, respectively, as plastics before their adaptation as paints, for reasons adduced earlier in this article, it would appear that heat-resisting paints will continue to play an important role in the inexpensive protection of all inherently heat-sensitive materials which are not suitable for impregnation.

The role of paint products, particularly varnishes, impregnation of electric equipment and the insulation of individual wires, has reached vital proportions. In the latter direction, application of flexible thermoplastics (such as nylon) from solution or by extrusion is already an established technique, although the bulk of impregnation is still carried out with conventional varnishes. Present developments in plastics are undoubtedly leading to new types of varnish for electrical insulation, which will provide properties not obtainable with those hitherto used. In this connection the use of melamine formaldehyde resins is likely to play an important part, and much will be heard of polystyrene derivatives.

It is only possible in an article of this type to indicate the situations which are likely to arise from the impact of plastics on paint, but sufficient has been said to support the opinion that it is not in the light of a reduction of the requirements for his product that the paint technologist views recent developments in the plastic field. Rather have they set new standards of permanence for organic materials, and it must be very seriously considered whether paint consumers may not rightly expect a very great advance in our conception of paint to arise.

It has been indicated above that the expression " plastic paint " is by no means new. Indeed, it has been applied in a haphazard way, particularly to water fast paints of the silicate, calcium sulphate or cement types, to describe certain performance characteristics based on their quick-setting properties; of particular interest has been the capacity of the film to be worked, as by stippling, in the intermediate period before final hardening.

In the light of the modern connotation of the word " plastic," such appellation can hardly be justified any longer, in view of the fact that there is now popularly implied a composition of organic materials of high molecular weight and of a very different general level of performance. No more can the expression be rightly applied to any paint which may be based on solutions of resins such as polyvinyl acetate or ethyl cellulose which also find application in plastic technology; nor to paints such as the bituminous type which may be applied hot and allowed to cool in situ as on roofs.

Whilst recognizing that it is neither possible nor profitable to essay a hard-and-fast definition of a plastic paint, there would seem to be indicated thereby a substantially solventless composition for cold application by normal brush or spray methods (as distinct from hot trowelling, hot spray or flame gun) which will form within a practical period

without heat polymerization a hard coherent film having the toughness and durability which has come to be associated with the term " plastic."

These performance requirements are sufficiently exact to indicate where the search for such a major development in paint technology must begin. They call for a stable polymerizable monomer or low polymer within the molar weight range 200-1,000 capable of being ground with pigment to give a paint of suitable viscosity for brush or spray application and of polymerizing in situ without volatilization in a manner similar to drying oils, but at a very much greater speed, to give a hard tough film.

Despite all the advances of recent years, glyceride drying oils are still the monomers which approximate most nearly to this specification. Most of the well-known polymerizable monomers are much too volatile to remain in the film sufficiently long to form a film by polymerization, even if this were possible under the conditions obtaining. Other approximations to the ideal are such bodies as allyl maleate, polyglycol maleate, and the low polymers of terpenes, but these have such disadvantages as poor hardening properties in the absence of heat, formation of brittle films and the like.

Probably the nearest practical approach to the concept of a plastic paint has been the development over the last decade of the acid—or cold-hardened—type of formaldehyde resin (phenol, urea or melamine). Such resins are low molecular condensation polymers of the resole type which are capable of increasing their molecular complexity to the infusible state under atmospheric conditions after the addition of small amounts of relatively strong acid catalysts. This development was pioneered largely by the Germans in their search for " ersatz " oil-free coatings and is claimed to have been used by such normally exacting consumers as the German State railway system. Critical details of any real value have not, however, been published, but experience has confirmed certain valuable properties of these materials which may be summarized as follow:—

(1) The high solid content (compared to nitro cellulose) of lacquers formed from them owing to the low molecular weight of the constituent resoles which are soluble in suitable paint solvents such as alcohol-ester mixtures.

(2) The ability to apply successive or wet-on-wet coats at short intervals and so build up a thick film of excellent body which hardens throughout its mass.

(3) The production of films having excellent gloss and freedom from curtain, sags and " orange peel " by suitable adjustment of catalyst concentration and solvents.

(4) The extreme final hardness equal to that of a fully or C stage formaldehyde-type resin and having comparable resistance to chemicals, heat and electricity.

At the present stage of their development such resins have found major application for use as aircraft glues, but for paint use they suffer from a number of disadvantages. Principal amongst these is the fact that the material to which catalyst has been added will slowly increase in viscosity and finally gelate in the can if not used in a fairly short time, or kept at a low temperature in a refrigerator. Moreover, the addition of catalyst is an exact and sensitive operation requiring particular care on the part of the operator. The catalyst being highly acidic in nature necessitates the provision of acid-resisting equipment, such as containers and spray guns. Although the final hardness is very great, speed of attaining it is not high. The majority of finishes now marketed need 16-24 hrs. to be handleable and only attain their final hardness in 5-7 days. The durability of the final film on outside exposure leaves much to be desired and the further protection of surfaces so heated is difficult owing to the high gloss of the film preventing adequate adhesion of superimposed coats. Finally, while the cost of the urea and melamine types

(Continued on p. 50.)

Resinoids and Other Plastics as Film Formers

By B. J. BRAJNIKOFF,
Consulting Electrical Engineer

XXII.—High-Elastic Deformation of Polymers *(contd.)*

Deformation Under Action of Periodic Forces

A close examination of the temperature and time regularities which affect high-elastic deformation has been conducted by Alexandroff and Lazurkin with the application of periodic forces, for which purpose these workers have built a device of special design for studying the elasticity within the temperature range from −180 degrees to +200 degrees absolute. In this apparatus a duly prepared specimen was subjected to the process of periodic deformation by compression, while the deforming force varied in time according to sinusoidal law. The frequency of the force variation was within the range from one cycle to one thousand periods per second, with the amplitude of oscillations being kept constant.

In the event of the periodic régime, instead of the dependence of deformation on the time and temperature in the form as given by the equation (5), we will obtain for the amplitude of the forced oscillations the expression:—

$$D = D_{el.} + \frac{D_{el.\infty}}{1 + i\omega\tau}, \qquad (6)$$

where $i = \sqrt{-1}$, ω is a circular frequency and τ—the time of relaxation. The formula (6) has a complex form owing to the circumstance that, as stated earlier, the relaxation deformation lags in phase from the applied load. In the elastic materials the lagging in phase is manifested by the fact of hysteresis and heat formation, i.e., the mechanical losses in the deformation, which are known as the irreversible Youle effect. A more convenient way for describing the regularities of deformation and mechanical losses is by resolving in the expression (6) the deformation D into the real part D′ and the imaginary quantity D″, in which case we have:—

$$D' = D_{el.} + \frac{D_{el.\infty}}{1 + \omega^2\tau^2} \qquad (7)$$

and

$$D'' = \frac{D_{el.\infty}\omega\tau}{1 + \omega^2\tau^2}. \qquad (8)$$

In order to depict the mechanism of deformation, a vector diagram, as that given in Fig. 3, may be employed to advantage; the diagrams of this kind have been introduced by Kuvshinsky[318] for the analytical treatment of the analogous processes of dielectric polarization and losses. In this diagram the segment $D_{el.}$ symbolizes the value of the elastic deformation, $D_{el.\infty}$ signifies the total magnitude of the elastic deformation. The observed deformation is denoted by the segment D. Every point on the circumference corresponds to a definite value of the product $\omega\tau$. At $\omega\tau \longrightarrow 0$ (low frequency or high temperature) we observe that $D = D_{el.\infty} + D_{el.}$. At $\omega\tau \longrightarrow \infty$ (high frequency or low temperature) $D = D_{el.}$. At the intermediate values of $\omega\tau$ the resultant deformation is taking a complex form, and its absolute magnitude is computed as $|D| = \sqrt{D'^2 + D''^2}$. The angle δ char-

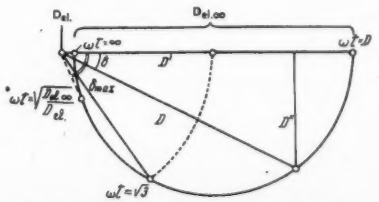

Fig. 3.—Vector diagram for the evaluation of high-elastic deformation.

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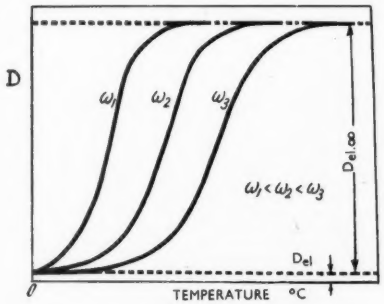

Fig. 4.—The relationship between the deformation and the temperature as derived from formulæ (7) and (8).

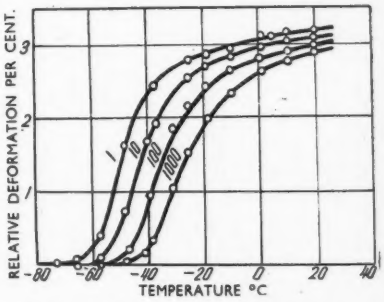

Fig. 5.—The relationship between the deformation of natural rubber with 3 per cent. of sulphur and the temperature. The parameter—frequency of oscillations per minute. Height of specimens 2.4 mm., diameter 12 mm.

acterizes the phase difference between the pressure vector, coinciding with the direction of the vector $D_{el.}$ and $D_{el.\infty}$, and the vector D.

The equations (7) and (8) allow the solution in an explicit form of the dependence $|D|$ on the temperature and frequency. The mechanism of this dependence of $|D|$ on the temperature at various frequencies is illustrated in Fig. 4.

In Fig. 5 are presented the results of the measurements of the deformation of natural rubber with 3 per cent. of sulphur, undergoing the periodic deformation by compression.

The nature of curves testifies that the general character of the dependence is correctly portrayed by the scheme. From Fig. 5 it may be seen that the material, which is elastic at low frequency oscillations, displays brittleness and glass-like properties at oscillations of higher frequency at the same temperatures. At greater values of ω the high-elastic deformation fails to develop, and the deformation is determined, in the main, by the ordinary elastic component. Similar results are obtained at high values of τ, i.e., at lower temperature levels.

This elastic deformation is of a lower order than that of high-elastic variety, approximately 2,000-fold, and for reasons of space its graphical representation has to be omitted. Therefore, at lowering of temperature the corresponding parts of the curves coincide with abscissæ. At small τ or at low frequencies, as would be expected from above considerations, the deformation is determined, fundamentally, by $D_{el.\infty}$.

In the Figs. 6, 7 and 8 are summarized the results of analogous measurements for the various other polymeric products: for the polymer of chloroprene derived by the polymerization at room temperature and subsequently kept for

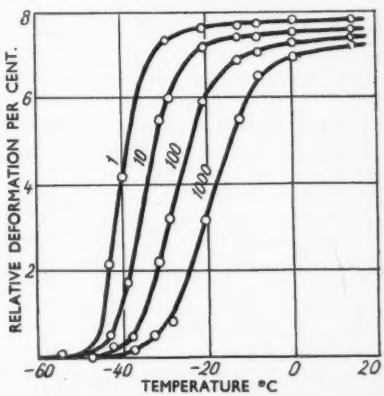

Fig. 6.—The same relationship, as in Fig. 5, for the polymer of chloroprene. Height of specimens 5.5 mm., diameter 12 mm.

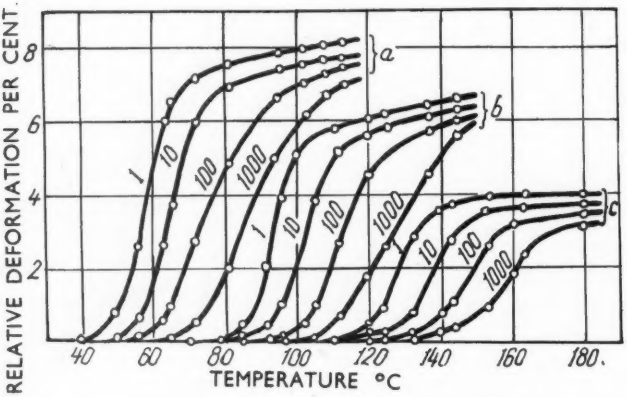

Fig. 7.—Relationship, as in Fig. 5, for poly-methyl-methacrylate: (a) 30 per cent. of plasticizer, (b) 10 per cent. of plasticizer, (c) without plasticizer. Height of specimens 4.5 mm., diameter 13 mm.

four hours at 145 degrees C. (Fig. 6), the polymer of methylmethacrylate containing different amounts of plasticizer (Fig. 7), and undervulcanized ebonite (Fig. 8). At elevated temperatures vulcanization in the latter continues, which leads to the decrease of deformation.

In all cases the general character of the regularity is being maintained. Solid at room temperature, methylmethacrylate at an elevated temperature displays the behaviour which is perfectly analogous to that of rubber. Their total moduli are very near in their numerical values. A similar behaviour exhibit also the polymers of styrol. The introduction of a plasticizer diminishes the total modul and increases the velocity of the attainment of deformation at a given temperature. The combined sulphur in rubber raises the modul and time of relaxation, i.e., displaces the performance curves towards higher temperatures.

The tested polymers greatly differ in their structure and physical properties. Among them there are three-dimensional polymers with the various amounts of interlinking bonds, as well as the linear polymers, both plasticized and free from plasticizers. For these reasons it is possible to assert that, in a considerable number of cases, the temperature and frequency dependence of the deformation of high-elastic substances is determined by the ratio between the relaxation time of the body and the period of the action of the force, i.e., absolutely does not reflect any structural changes. In all these cases there exists no definite temperature level (or temperature range) for passing from the elastic state into the "solid." In all examined instances the temperature of the transition is determined not only by the nature of a substance, but by the method of the measurement as well (by the value of frequency or the time of application).

This regularity is perfectly general for all amorphous bodies and should be taken into consideration in the designing of any articles from plastic masses and elastic

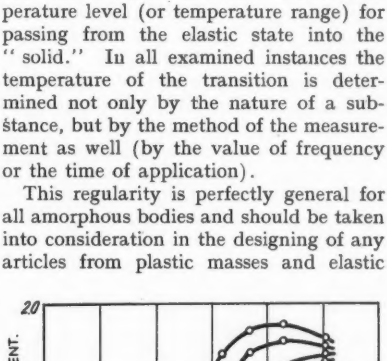

Fig. 8.—Relationship, as in the Fig. 5, for under vulcanized ebonite. Height of specimens 4.6 mm., diameter 12 mm.

materials, in particular, of multitudinous rubber-like products designed for use under the dynamic conditions of service, as, for example, the impregnated transmission belts, transporter and conveyer fabrics, shock absorbers, etc.

The raising of the frequency of the force applied is equivalent to the lowering of temperature. Within certain limits the increase of the frequency is manifested relatively little in the behaviour of an elastic substance, which has been revealed in a number of works[327] devoted to the subject. However, when $\frac{1}{\omega}$ approaches in the numerical value that of τ, the behaviour of a material drastically changes. Thus, for example, at room temperatures the variation of the frequency from a single cycle up to one thousand periods per minute leads to the alteration of the modulus of the natural (free from fillers) rubber by 10 per cent., but at -40 degrees absolute at a similar variation of frequency the modulus changes 10-fold. (See Fig. 5.) This circumstance limits the possibility of the application of the natural rubber in the given range of frequencies and the temperatures.

The above considerations hold true not only in the cases of small deformations through compression, or torsion, but also apply to stretching of rubber under the load resulting in the elongation of specimens by hundred per cent. In the experiments performed in the laboratory of Alexandroff and Lazurkin, the time was recorded from the moment of application of force till the moment of registering the deformation at different temperatures. The results of these experiments are summarized in Fig. 9.

The same regularity was observed by Marey in the performance by synthetic rubber-like plastics. The experiments of Metenyi[325] have demonstrated that the analogous regularities are obtained also in the studying of deformation through bending of bakelite at elevated temperatures. Thus the scheme, as evolved by Alexandroff and Lazurkin, in the qualitative sense conforms with the results of experiments.

Estimation of Mechanical Losses

The same analytical scheme provides a general course of regularities for the mechanical losses in the deformation of high-elastic materials. As has been indicated earlier, the angle δ, which signifies the phase difference between the applied force and deformation, can be either measured directly, or its value may be calculated with the aid of the equations (7) and (8):—

$$\tan \delta = \frac{D''}{D'} = \frac{D_{el.\infty}\omega\tau}{D_{el.}(1 + \omega^2\tau^2) + D_{el.\infty}} \quad (9)$$

This value of tan δ passes through a maximum at

$$\omega\tau = \sqrt{\frac{D_{el.\infty}}{D_{el.}}} + 1 \quad (10)$$

In the vector diagram of Fig. 3 the maximum of angle losses corresponds to the case, when vector D is tangent to the circumference (the vector is indicated

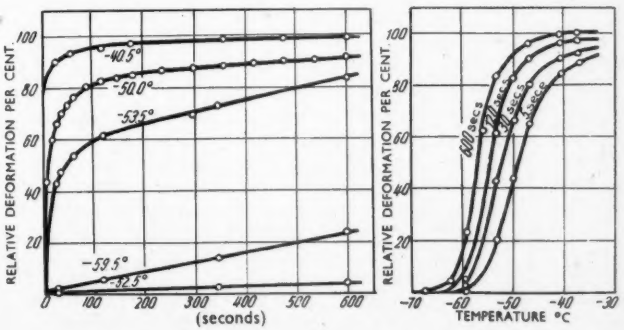

Fig. 9.—Relationship of stretching of natural rubber (3 per cent. sulphur) with time (left) and with temperature (right).

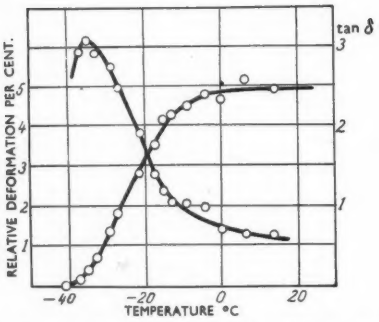

Fig. 10.—The deformation of rubber with 3 per cent. of sulphur, and the angle of mechanical losses in it at the frequency of 2,000 oscillations per minute (the ascending curve indicates deformation, the descending—losses).

by the dotted line). It may be seen from the diagram that the observed deformation in this instance forms a very small part of the total deformation, and the tan δ is approaching the right angle, for $D_{el.}$ for rubber is small in comparison with $D_{el.\infty}$. Alexandroff and Lazurkin have measured the mechanical losses for the natural rubber with 3 per cent. of sulphur. From the accompanying Fig. 10 it may be seen that the maximum angle of mechanical losses is very large and is reached at small deformation values. The mechanical losses in other polymeric materials, according to observations of Alexandroff and Lazurkin, also pass through a maximum at a certain temperature level, as should be expected in conformity with the above-developed scheme.

Conclusions

If the experimental curves of the relationships between the deformation and the temperature were accurately described by the developed formulas, then with their help, neglecting $D_{el.}$, it would be easy to determine the time of relation τ at various temperatures by fulfilling the condition at

$$\omega\tau \approx \sqrt{3}\,|D| = \frac{D_{el.\infty}}{2} \qquad (11)$$

(the symbol $\approx$ denotes approximation).

However, since the scheme portrays only a general course of regularities, and not its details, it follows that τ, as determined by the expression (11) from experimental curves, has merely conditional and restricted sense. Nevertheless, knowing its value at different temperatures, it is possible to judge the performance of polymeric materials at various temperature-frequency régimes.

Fig. 9 depicts the dependence of log $\tau = f\left(\frac{1}{T}\right)$ for the examined polymers.

This figure shows that within relatively small ranges of temperature in these co-ordinates there are obtained straight line curves, i.e., they obey the exponential law:

$$\tau = Ae^{\frac{U}{kT}}.$$

Unfortunately, the energy of the activation cannot be determined accurately

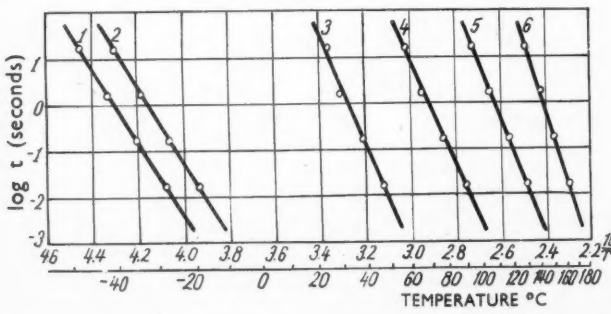

Fig. 11.—Relaxation time of various polymers and the temperature. 1, Natural rubber with 3 per cent. of sulphur; 2, chloroprene; 3, undervulcanized ebonite; 4, methyl-methacrylate with 30 per cent. of a plasticizer; 5, methyl methacrylate with 10 per cent. of a plasticizer; 6, without plasticizers.

from the angle of the slope of straight lines, because both within a larger temperature range, as well as in simple amorphous bodies, the performance loci are deviating from the straight line, i.e., U somewhat depends on the temperature, and in this event the angle coefficient of a tangent, as it can be readily seen, is not equal to $\frac{U}{k}$.

These straight lines afford the possibility of determining at any given frequency that temperature at which the observed elastic deformation constitutes one half of the total.

In order to determine the required temperature from the diagram, the first step is to calculate the value of $\tau = \frac{\sqrt{3}}{\omega}$, and the corresponding abscissa in Fig. 11 gives the required temperature. Every point of area of the figure corresponds to a definite temperature and frequency of the application. The points located to the right and above of a straight line, correspond to the régime, when the observed deformation of a given polymeric product exceeds one-half of the total and tends to a total deformation as the distance between the point and straight line increases. The points lying to the left and below the straight line correspond to the conditions, when the observed deformation constitutes less than one-half of the total, and tends to the value of the elastic deformation, as the distance between the point and straight line increases.

The above-presented data, as worked out by Alexandroff and Lazurkin, do not cover all the deductions which are possible on the basis of the foregoing considerations.

It should be remarked that the reduction of the observed elastic deformation may be associated not only with a gradual diminution of the probability of the regrouping of particles at the lowering of temperature, but also with the cessation of regroupings connected with crystallization.

In this respect are very interesting the results of measuring the dynamic modulus of the three-dimensional polymer obtained by the polymerization of chloroprene at room temperature during a long period.

In Fig. 12 are given two groups of the curves derived from this material. The bottom curves drastically differ in their shape from the usual performance curves of polymers. The specimen, in which, after a lengthy keeping at room temperature, there were centres of crystallization, developed a very rapid crystallization, which leads to a strong growth of the modulus without manifesting dependence on frequency; it results in the increase of density. The experiment showed that in this event the modulus may increase scorefold. At still

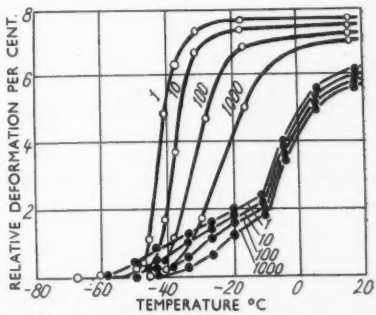

Fig. 12.—Typical performance curves portraying the results of measuring dynamic modulus of a three-dimensional polymer (chloroprene).

lower temperatures there appears a considerable dependence upon frequency on account of the residual amorphous phase. The heating of this specimen up to room temperature gave the deformation values appreciably lower than the initial values (denoted in the diagram by the circumscribed points), i.e., the formed crystalline phase is not fusible even at room temperature. The heating of the specimen for 15 minutes at 60 degrees C. gave the total restoration of elastic properties. The top curves are yielded by the specimen so heated, while the temperature range, within which there was

observed the maximum velocity of crystallization, has been passed very rapidly. The picture thus obtained is of a typical nature and is characteristic of other polymeric amorphous bodies.

This example has been cited in order to illustrate the case of the loss of elasticity, which is associated with the structure. As it is seen from Fig 12, the regularities attending this case are radically different from those described before. These phenomena are well observed in the natural and chloroprene rubbers. The second case is very rarely observed in the small deformations, but in the large deformations (300 per cent. and over) it plays an essential role.

The relaxation regularities of high elastic deformation are perfectly analogous to the regularities of other orientational relaxation processes, which is due to the circumstance that the physical nature of these phenomena is identical. Thus, for example, the polarization of dipole amorphous dielectrics in the electric field is satisfactorily depicted by the Debye theory, which has been applied by Alexandroff and Lazurkin to the interpretation of mechanism of high-molecular deformation (except the consideration of the internal field). The same regularities, but free from restrictions of small fields, may apparently be valid for interpreting the double refraction of rays during the deformation of polymers, as well as a series of other phenomena accompanying the orientation, thus confirming the correctness of the trend in research and indicating new possibilities in the technology of plastic materials.

(To be continued)

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PLASTICS AND PAINT—*(Continued from p. 43)*

remain high, use of the cheaper phenolic type is likely to give rise to discoloration on exposure to sunlight.

It is probably fair to summarize the position of this type of development in relation to our hypothetical "plastic paint" by saying that it represents the latest and most practical advance in the adaptation of condensation polymers to this end, whereas it is probably from an intensive study of additive monomers, especially of the convertible type, that the main evolution will eventually occur. This recognizes the pre-eminence of glyceride drying oils as additive monomers of the type required.

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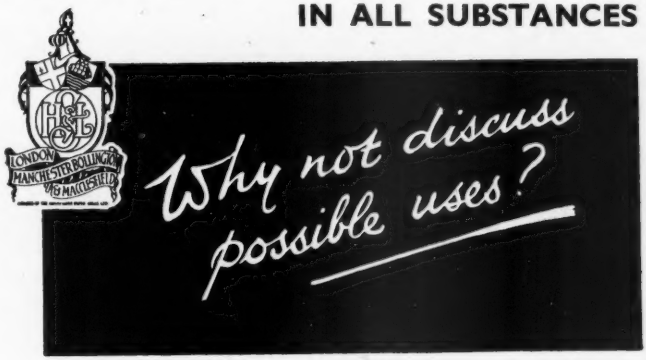

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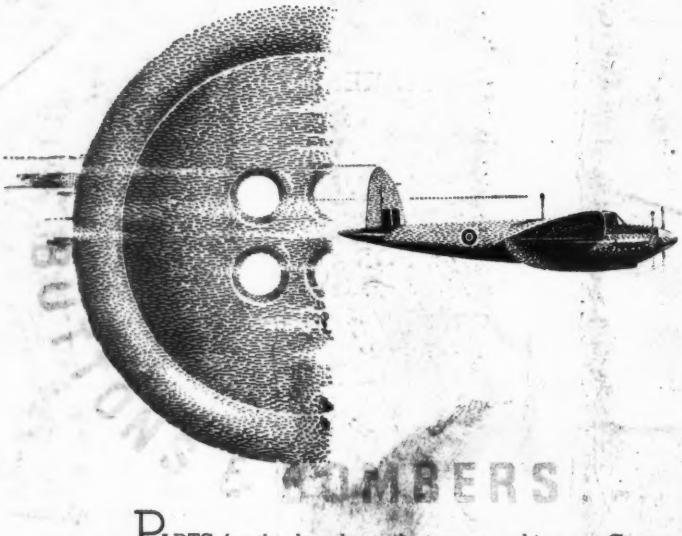

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